Geographica: Science and Education Journal
GSEJ
Website: http://usnsj.id/index.php/geographica
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ANALYSIS OF GROUNDWATER POTENTIAL USING THE WENNER CONFIGURATION RESISTIVITY GEOELECTRIC METHOD IN THE WATUBANGGA AREA, KOLAKA, SOUTHEAST SULAWESI

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ARTICLE INFO

ISSN: 2716-4837
Vol. 8, No. 1, June 2026
URL: http://usnsj.id/index.php/geographica

Suggestion for the Citation and Bibliography
Citation in Text: Salu, S. P., Arif., & Aswar, M. (2026)
Biliography: Salu, S. P., Arif., & Aswar,. M. *(2026),* Analysis Of Groundwater Potential Using The Wenner Configuration Resistivity Geoelectric Method In The Watubangga Area, Kolaka, Southeast Sulawesi. *Geographica: Science & Education Journal,* 8(1, June) 13-23.

Abstract

Groundwater is an important water resource in Watubangga District, Kolaka Regency, Southeast Sulawesi, especially in areas with limited surface water availability. This study aims to identify aquifer zones and analyze groundwater potential using the Wenner configuration geoelectrical resistivity method. Data acquisition was carried out on three survey lines (GL-01, GL-02, and GL-03), each with a length of 480 m and electrode spacing of 30 m. The data were processed using RES2DINV software to obtain a two-dimensional subsurface resistivity model. The results showed resistivity values ranging from 1.61 Ωm to 3177 Ωm. Aquifer zones were identified at depths of 20–74.6 m with low resistivity values of 7.55–78.8 Ωm, interpreted as water-saturated clay and loose sand layers. GL-02 exhibited the best groundwater potential due to its extensive lateral distribution and aquifer continuity at depths of 20–70 m. In contrast, GL-03 showed limited groundwater potential with narrower aquifer distribution. The interpretation results correlate well with the hydrogeological and geological conditions of Watubangga District, indicating moderately productive aquifers associated with alluvial deposits and fractured sandstone formations.

Keywords: Aquifer, Geoelectric Resistivity, Groundwater Potential, Watubangga District, Wenner Configuration

A. Introduction

Groundwater remains crucial in Kolaka Regency, particularly in Watubangga District. Relying solely on PDAM water to meet the needs of raw water, irrigation, and industry in Watubangga District is insufficient. Therefore, groundwater potential estimation and mapping are necessary to provide an overview of groundwater conditions in the area. The distribution of groundwater-bearing rock layers can be determined by conducting geoelectric measurements. (Usman et al. 2017).

Geoelectric methods have been widely used to investigate aquifer layers, both through sounding and mapping. In this study, groundwater identification was based on the distribution of resistivity values. This method was chosen because groundwater is generally conductive and has lower resistivity values. The use of the Schlumberger configuration is expected to identify resistivity distribution through sounding, thus predicting the presence of groundwater aquifers. (Muhardi, Perdhana, and Nasharuddin 2020). The resistivity value of rocks/materials is not always the same. The resistivity value of each rock is not necessarily the same, and conversely, different rocks can have the same resistivity value, this can be influenced by the presence of water in the rock. (Alfaiz and Hutahaean 2015).

Groundwater is a natural resource that plays a vital role in supporting human life, including domestic, agricultural, industrial, and other activities. With population growth and the increasing need for clean water, exploration and evaluation of potential groundwater reserves are crucial, especially in areas with favorable geological potential. However, groundwater cannot be directly observed because it is located beneath the surface. Therefore, geophysical exploration methods are needed that can indirectly identify subsurface structures. One commonly used method is the geoelectric resistivity method, which utilizes the electrical resistivity properties of subsurface rocks to identify the type and composition of soil layers and determine potential aquifer zones. Groundwater is also water found in soil pores and rock crevices beneath the surface. Knowledge of the distribution and depth of aquifers (water-bearing layers) is the basis for exploring groundwater resources. (Todd & Mays, 2005).

The Wenner configuration is a type of electrode configuration in the resistivity method that is widely used due to its sensitivity to changes in vertical layers. Through this configuration, resistivity measurements can produce a 2D cross-section of the soil layer structure, allowing researchers to interpret the presence and thickness of water-saturated layers (aquifers), as well as estimate available groundwater reserves. One method used to determine subsurface conditions is the geoelectric resistivity method, which works based on measuring electrical resistance in the soil. This technique is widely used because it is relatively inexpensive, efficient, and does not damage the environment. (Telford, W.M 1990).

By measuring resistivity and interpreting the data using software such as RES2DINV, the distribution of resistivity values can be accurately mapped and provide a picture of the subsurface geological conditions. This is extremely useful in determining appropriate locations for well drilling or sustainable groundwater management. Although several previous studies have applied geoelectrical resistivity methods to identify groundwater potential, most studies in Indonesia commonly used the Schlumberger or Dipole–Dipole configurations due to their effectiveness in vertical sounding and structural mapping. However, studies specifically applying the Wenner configuration for groundwater investigations in the Watubangga area are still very limited. In addition, the hydrogeological characteristics of Watubangga District, which are dominated by alluvial deposits, sandstone, and fractured rock formations, require a configuration that is sensitive to lateral and vertical resistivity variations associated with aquifer distribution. The Wenner configuration was selected in this study because it has a high sensitivity to subsurface layer changes, provides good signal strength, and is more stable in detecting shallow to medium-depth aquifer zones in areas with heterogeneous lithology. Therefore, the novelty of this study lies in the application of the Wenner configuration resistivity method to characterize groundwater potential and aquifer continuity in Watubangga District through integrated interpretation of geoelectrical data, hydrogeological maps, and regional geological conditions. This approach is expected to provide more accurate information for groundwater exploration and sustainable water resource management in the study area.

B. Methodology

1. Research Design

This study employed a quantitative geophysical approach using the geoelectrical resistivity method with the Wenner configuration to identify subsurface lithology and groundwater potential in Watubangga District, Kolaka Regency, Southeast Sulawesi. The research design focused on field data acquisition and two-dimensional resistivity modeling to interpret aquifer distribution based on variations in subsurface electrical resistivity values. The quantitative approach was selected because the study relies on numerical measurement data obtained directly from geoelectrical instruments and processed mathematically through inversion modeling using RES2DINV software.

Field measurements were conducted through direct geoelectrical surveys along predetermined survey lines. The observed parameters included electric current (I), potential difference (ΔV), apparent resistivity values, subsurface layer depth, and resistivity distribution patterns. The interpretation process was carried out by correlating the resistivity model with regional geological and hydrogeological conditions to identify aquifer zones and groundwater-bearing formations.

2. Instruments

The geoelectrical measurements were conducted using an S-Field resistivity meter operated through the Geo-Resistivity application. Data acquisition applied the Wenner electrode configuration due to its high sensitivity to both vertical and lateral resistivity variations, making it suitable for groundwater exploration in heterogeneous lithological environments such as the Watubangga area.

Each survey line had a total length of 480 m using 16 electrodes with an electrode spacing of 30 m. The selection of 16 electrodes was intended to obtain sufficient subsurface coverage and measurement efficiency during field acquisition while maintaining stable data quality. Meanwhile, the 30 m electrode spacing was selected to achieve deeper penetration depths and effectively identify medium-depth aquifer zones. This spacing was considered appropriate for regional-scale groundwater investigations in areas dominated by alluvial deposits, sandstone, and fractured rock formations. The wider spacing also enabled the identification of lateral aquifer continuity across the study area.

The selection of a 30 m electrode spacing theoretically provides an effective depth of investigation of approximately 45–60 m for the Wenner array based on the practical approximation depth $\approx n \times a / 2$, where a is the electrode spacing and n is the level factor. However, the maximum depth displayed in the RES2DINV inversion model reached approximately 95.6 m. This difference occurs because the inversion process in RES2DINV estimates subsurface resistivity distribution beyond the effective penetration depth through mathematical interpolation and sensitivity distribution of the measured data. Therefore, the deeper section in the inversion model represents interpreted resistivity continuity rather than direct measurement sensitivity. In this study, the main aquifer interpretation was focused on depths with relatively high data sensitivity, particularly within the range of 20–74.6 m, while deeper layers were interpreted more cautiously as supporting geological information.

At each measurement level, the Wenner array automatically increases the effective electrode separation factor (na) during acquisition, allowing deeper current penetration and broader subsurface coverage. Consequently, although the base electrode spacing remained 30 m, the effective investigation depth increased progressively with larger electrode intervals during the measurement sequence. The field data obtained from each measurement line were processed using RES2DINV software to produce two-dimensional subsurface resistivity sections. The inversion results were then interpreted to determine lithological characteristics, aquifer depth, groundwater distribution patterns, and the correlation between resistivity values and hydrogeological conditions in the study area. The distribution map of the route is as follows:

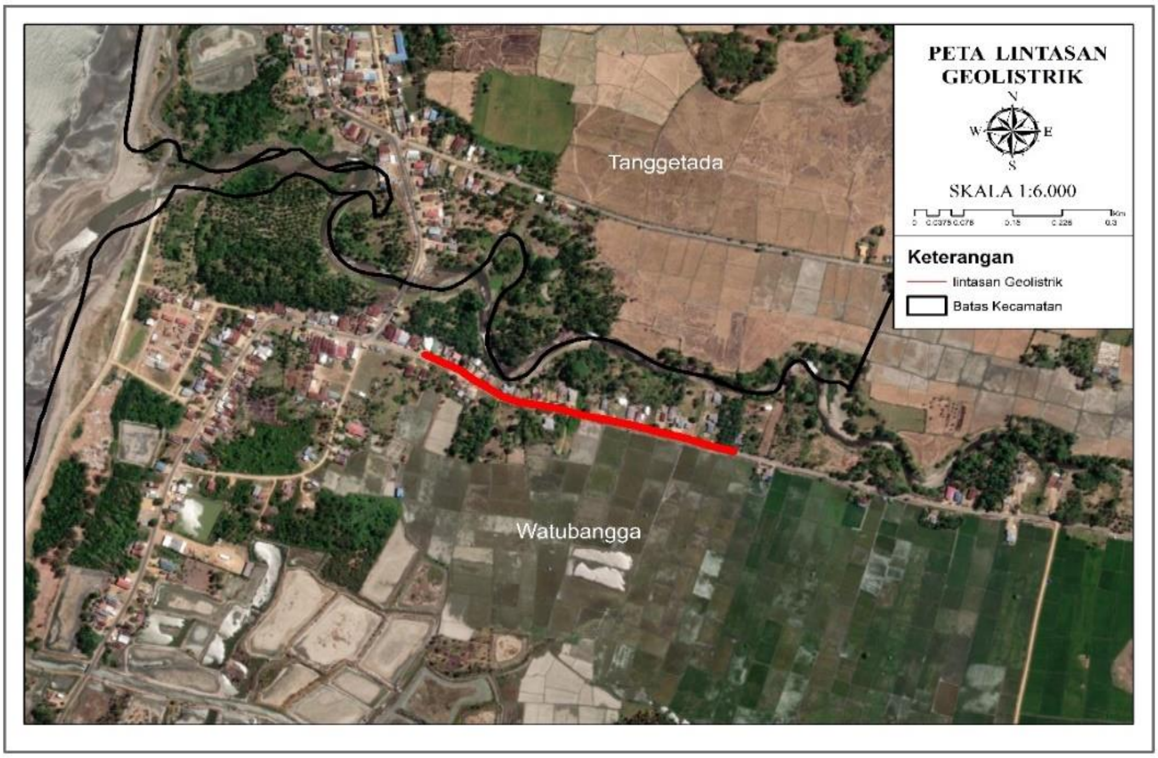

Figure 1. *Geoelectric path in village wolulu* (Source: data analysis)

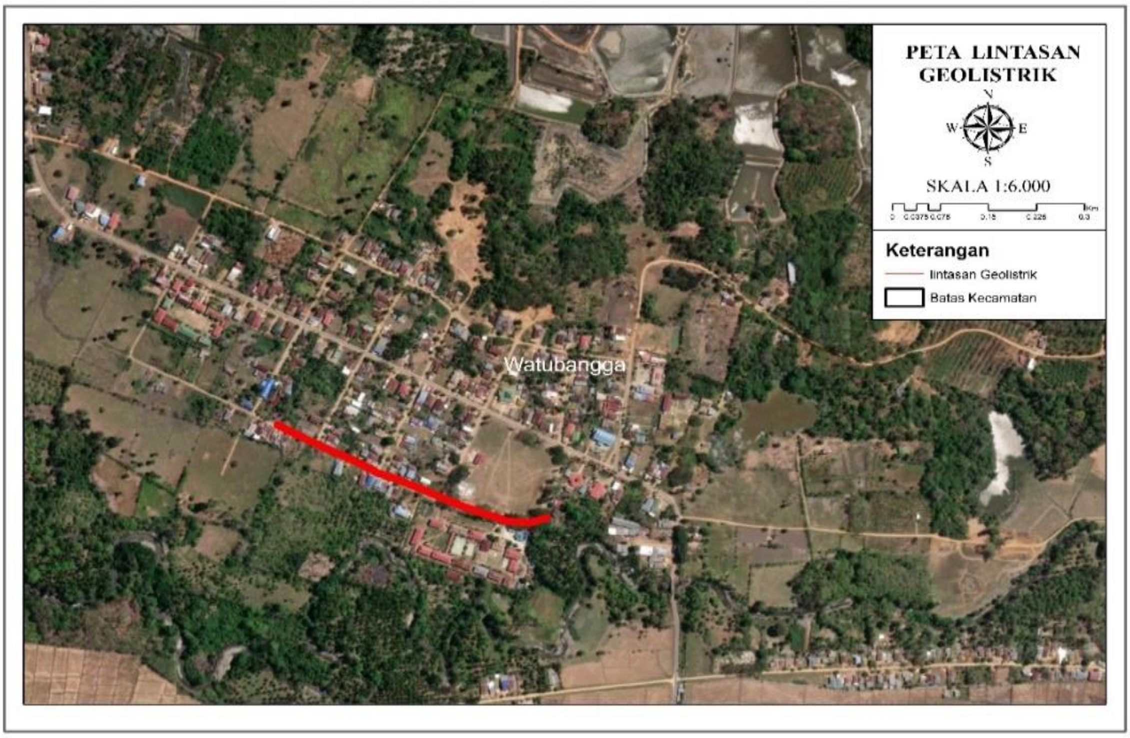

Figure 2. *Geoelectric path in Watubangga sub-district* (Source: data analysis)

Figure 3. *Geoelectric path in Gunung Sari village* (Source: data analysis)

3. Technique of Data Analysis

Data collection used the Wenner configuration method, employing 16 electrodes with a 30m spacing between electrodes. This spacing was chosen to achieve sufficient penetration depth to identify the main aquifer layers along the research path. The potential difference (ΔV) and electric current (I) values were obtained directly from the geoelectrical instrument readings using the GeoResistivity application during field measurements. These values were then converted to units (Volts and Amperes). The Wenner configuration geometry factor formula is as follows:

$K = 2\pi(a)$ ………………………………………………… (1.1) *(Reynolds, 2011)*

This geometric factor is used in calculating the apparent resistivity for all research paths, namely GL-01, GL-02, and GL-03. Thus, each current-voltage data measured at the current electrode can be converted into an apparent resistivity value through the following equation:

$\rho_a = 2\pi a \cdot \frac{\Delta V}{I}$ …………………………………………... (1.2) *(Reynolds, 2011)*

a = spacing between electrodes
ΔV = obtained from the tool
I = obtained from the tool

Apparent resistivity calculations are performed automatically by the tool/application and used as input for 2D inversion.

These apparent resistivity values are used as field measurement data, which are the primary input for the 2D inversion process. These values do not yet represent the actual rock resistivity, but are used to construct a subsurface resistivity model, which is then interpreted geologically and hydrogeologically. Data collection for each geoelectrical path is carried out using the GeoResistivity application.

C. Findings and Discussion

1. Findings

The results of resistivity modeling show the distribution of resistivity values as follows:

1) The Gl-01 station trajectory on the distribution of subsurface resistivity values with a depth of up to 95.6m and a trajectory length of 480m using an electrode spacing of 30m. The resistivity color scale is shown at the bottom of the image with resistivity values in Ohm.m (Ω.m):

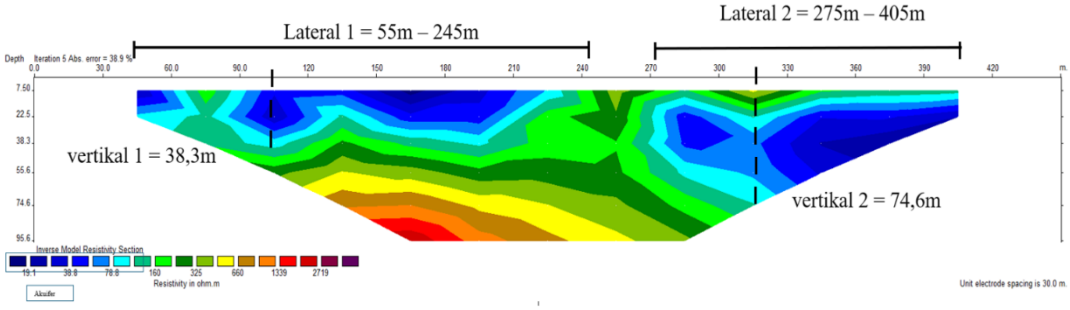

Figure 4. *Geoelectric Results on the Wolulu Village Route (GL-01)*
(Source: data analysis)

Table 1*. Distribution of Subsurface Resistivity Values Gl-01*

Colours	Depth (m)	Resistivity value (Ω.m)	Stratigrafi	Reference (Telford, 1990)
→	22,5m - 74,6m	19.1 - 78.8	Claystone	Clay / Loose sand is saturated with water (1-100 / 10-100)
→	74,6m - 90m	78.8 - 325	Sandstone	Water-saturated gravel / Sandstone (100-600 /8-4000)
→	90m - 95,6m	325 - 1339	Marmer Basalt	Marmer/basalt (100-2000 / 200-2000)
→	>95,6m	1339 - 2719	Granit	Granit / (500-100000)

a. Resistivity value:
   a) Resistivity range: 19.1 - 2719 Ohm.m
   b) Low value (19 - 78 Ohm.m): indicates the presence of an aquifer
b. Depth and layers of aquifer indication
   a) Aquifer zone at 22.5m – 74.6m
   b) Resistivity: 19 – 78 Ohm.m (dark blue – light blue)
   c) loose sand saturated with water or clay
c. Lateral and vertical distribution
   a) Lateral zone 1 is at 55m – 245m and the vertical aquifer is at a depth of 38.3m.
   b) Lateral zone 2 is at 275m – 405m and the vertical aquifer is at a depth of 74.6m.
d. Correlation of hydrogeological maps and geological maps
   a) GL-01 shows a layer of water-saturated sandy clay that is porous and permeable - the main characteristics of an intergranular aquifer on the hydrogeological map.
   b) Alluvium (Qa), consisting of sand, gravel, silt, and clay in the lowlands and coastal areas on the geological map. This unit is a productive aquifer, according to the GL-01 geoelectric results which show a layer of loose sand saturated with groundwater.

2) The Gl-02 station trajectory on the distribution of subsurface resistivity values with a depth of up to 95.6m and a trajectory length of 480m using an electrode spacing of 30m. The resistivity color scale is shown at the bottom of the image with resistivity values in Ohm.m (Ω.m):

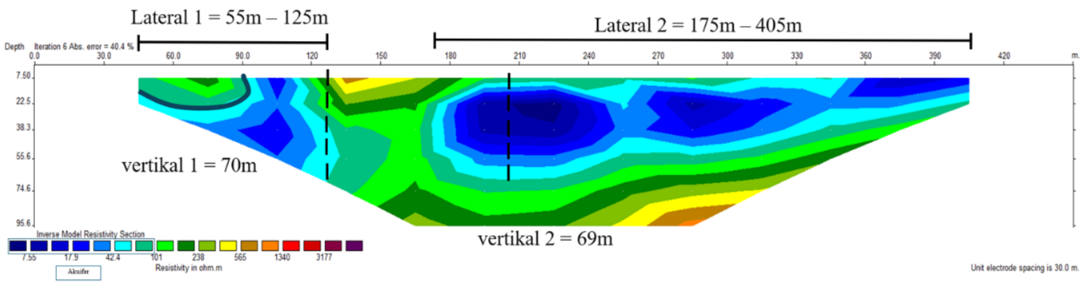

Figure 5. *Geoelectric Results on the Watubangga sub-district route (GL-02) (Source: data analysis)*

Table 2. *Distribution of Subsurface Resistivity Values Gl-02*

Colours	Depth (m)	Resistivity value (Ω.m)	Stratigrafi	Reference (Telford, 1990)
→	20m - 70m	7,55 - 42,4	Claystone	Clay / Loose sand is saturated with water (1-100 / 10-100)
→	70m - 90m	42,4 - 238	Sandstone	Sandstone (8 - 4000)
→	90m - >95,6m	238 - 1340	Marmer Basalt	Basalt / Marmer (200-2000 / 100-2000)
→	>95,6m	1340 - 3177	Granit	Granit / (500-100000)

a. Resistivity value:
   a) Resistivity range: 7,55 - 3177 Ohm.m
   b) Low value (7,55 – 42,4 Ohm.m): indicates the presence of an aquifer
b. Depth and layers of aquifer indication
   a) Aquifer zone at 20m - 70m
   b) Resistivity: 7,55 – 42,4 Ohm.m (biru tua – biru muda)
   c) loose sand saturated with water or clay
c. Lateral and vertical distribution
   a) Lateral zone 1 is at 55m – 125m and the vertical aquifer is at a depth of 70m.
   b) Lateral zone 2 is at 175m – 405m and the vertical aquifer is at a depth of 69m.
d. Correlation of hydrogeological maps and geological maps
   a) GL-02 shows a layer of water-saturated sandy clay that is porous and permeable - the main characteristics of an intergranular aquifer on the hydrogeological map.
   b) Alluvium (Qa), consisting of sand, gravel, silt, and clay in the lowlands and coastal areas on the geological map. This unit is a productive aquifer, according to the GL-02 geoelectric results which show that some of the loose sand layers are saturated with groundwater.

3) The Gl-03 station trajectory on the distribution of subsurface resistivity values with a depth of up to 95.6m and a trajectory length of 480m using an electrode spacing of 30m. The resistivity color scale is shown at the bottom of the image with resistivity values in Ohm.m (Ω.m)

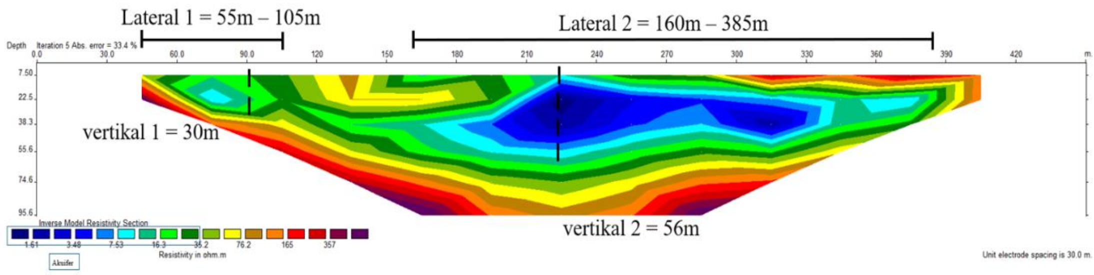

Figure 6. *Geoelectric Results on the Gunung Sari Village Route (GL-03)*
(Source: data analysis)

Table 3. *Distribution of Subsurface Resistivity Values Gl-03*

Colors	Depth (m)	Resistivity value (Ω.m)	Stratigrafi	Reference (Telford, 1990)
→	22,5m - 56m	16,1 - 35,2	Claystone	Clay / Loose sand is saturated with water (1-100 / 10-100)
→	56m - >95,6m	35,2 - 165	Sandstone	Sandstone (8-4000)
→	>95,6m	165 - 357	Marmer Basalt	Marmer / basalt (100-2000 / 200 - 2000)

a. Resistivity value:
   a) Resistivity range: 1,61 - 357 Ohm.m
   b) Low value (1,61 – 35,2 Ohm.m): indicates the presence of an aquifer
b. Depth and layers of aquifer indication
   a) Aquifer zone at 22,5m – 56m
   b) Resistivity: 1,6 – 35,2 Ohm.m (biru tua – hijau muda)
   c) loose sand saturated with water or clay
c. Lateral and vertical distribution
   a) Lateral zone 1 is at 55m – 105m and the vertical aquifer is at a depth of 30m.
   b) Lateral zone 2 is at 160m – 385m and the vertical aquifer is at a depth of 56m.
d. Correlation of hydrogeological maps and geological maps
   a) GL-03 shows a local low resistivity zone which also corresponds to the area marked on the hydrogeological map as a local aquifer with low productivity.
   b) The Buara Formation (QI), consisting of coral reefs, conglomerates, and sandstones on the geological map. This unit has secondary fractures and pores, thus functioning as a moderately productive fractured aquifer, according to the interpretation of GL-03.

2. Discussion

1) Correlation of Geoelectric Interpretation Results with Hydrogeological Maps and Geological Maps

Based on the Kolaka Regency Hydrogeological Map (Bappeda, 2023), Watubangga District is located in an aquifer zone with flow through intergranular spaces (pores) and fractures, with moderate to high productivity (light blue and partly light green on the map). This condition aligns well with the geoelectric results, where GL-01 and GL-02 indicate layers of water-saturated sandy clay that are porous and permeable—the main characteristics of intergranular aquifers.

The low resistivity zone in GL-03, which is local in nature, also corresponds to an area marked on the hydrogeological map as a low-productivity local aquifer. This confirms that the geoelectric interpretation results align with regional hydrogeological conditions.

The spatial correlation between GL-01, GL-02, and GL-03 indicates that the aquifer zones identified in the study area show relatively continuous lateral distribution, particularly between GL-01 and GL-02. Both survey lines exhibit low resistivity values ranging from approximately 7.55–78.8 Ωm at depths of 20–74.6 m, which are interpreted as water-saturated sandy clay and loose sand layers. The similarity of resistivity characteristics and aquifer depths suggests that these zones may belong to the same interconnected intergranular aquifer system distributed within the alluvial deposits of Watubangga District.

In contrast, GL-03 shows a more localized low-resistivity zone with narrower lateral continuity and relatively shallower aquifer distribution. This condition is interpreted to be influenced by the lithological characteristics of the Buara Formation, which consists of sandstone, reef limestone, and fractured rocks. Consequently, groundwater occurrence in GL-03 is likely controlled by secondary porosity and fracture systems rather than extensive intergranular pore spaces. Spatially, the overall resistivity pattern indicates that groundwater potential is more dominant in the central and lowland areas represented by GL-01 and GL-02, while GL-03 represents a localized fractured aquifer system with lower productivity.

According to the Kolaka Regional Geological Map (Geological Survey Center, Simandjuntak, 1993), the Watubangga area, where the study site is located, is composed of two main geological units:

a. Alluvium (Qa), consisting of sand, gravel, silt, and clay in the lowlands and coastal areas. This unit is a productive aquifer, in accordance with the geoelectric results of GL-01 and part of GL-02 which show a layer of sand saturated with groundwater.
b. Buara Formation (QI), consisting of coral reefs, conglomerates, and sandstones. This unit has secondary fractures and pores, thus functioning as a moderately productive fractured aquifer, according to the interpretation results of GL-03.

The low resistivity values identified in this study are consistent with the hydrogeological theory that groundwater-saturated sediments generally exhibit lower resistivity due to increased electrical conductivity caused by pore water content. According to Telford and Todd, unconsolidated sand, clay, and alluvial deposits commonly show resistivity values below 100 Ωm when saturated with groundwater. The resistivity ranges obtained from GL-01 and GL-02 (7.55–78.8 Ωm) therefore strongly indicate productive aquifer zones dominated by saturated loose sand and clay materials.

The results of this study are also comparable with previous groundwater investigations using geoelectrical resistivity methods in Indonesia. Research conducted by Muhardi et al. (2020) showed that low resistivity zones in the range of 10–100 Ωm were associated with groundwater-bearing formations in unconsolidated sediments. Similarly, studies by Usman et al. (2017) demonstrated that aquifer zones interpreted from low resistivity anomalies commonly correspond to porous and permeable lithologies capable of storing groundwater. Therefore, the consistency between the present results, hydrogeological theory, and previous studies strengthens the interpretation that the identified low-resistivity zones in Watubangga District represent potential aquifer systems.

2) Integrative Analysis

By combining the results of geoelectric interpretation, hydrogeological maps, and geological maps, it can be concluded that:

a. The main aquifer in each path is found in a layer of groundwater-saturated sand / clay with a resistivity of 10-200 / 1-100 Ω·m and a depth of (20m - 70m).
b. The Tmpe Formation functions as an aquitard at the bottom of the aquifer, limiting the vertical flow of groundwater.

c. The highest aquifer potential is found on the GL-01 and GL-02 routes which have the best lateral continuity.
d. The resistivity distribution pattern on the three paths corresponds to the aquifer zone with flow through the intergranular space on the hydrogeological map.

Regionally, these results demonstrate a good agreement between the geoelectric model and hydrogeological patterns, confirming that the groundwater potential of Watubangga District falls into the following categories: (moderately productive aquifer with extensive distribution), an aquifer zone with flow through intergranular spaces, and an aquifer with flow through fractures and channels (locally, a productive aquifer).

Overall, this study demonstrates the effectiveness of the Wenner configuration geoelectric resistivity method in identifying aquifers. The aquifers in Watubangga District are distributed at medium depths with low resistivity ranging from 19.1 to 78 Ω m. Of the three trajectories, GL-02 can be recommended as the area with the best groundwater potential due to its extensive lateral distribution and good continuity.

D. Conclusion

Based on the results of geoelectric resistivity modeling with Wenner configuration on the GL-01, GL-02, and GL-03 lines in the Watubangga District, Kolaka Regency, several important conclusions can be drawn as follows:

1) The GL-01 route shows the potential for a fairly large water-saturated aquifer and resistivity values between 19 – 78.8 Ω·m at a depth of around 22.5 – 74.6 meters, this indicates a layer of water-saturated loose clay and sand that is capable of storing groundwater.
2) The GL-02 line shows a potential aquifer with a resistivity value of 7.55–42.4 Ω·m at a depth of approximately 22–70 meters. This indicates a layer of water-saturated clay and loose sand capable of storing groundwater.
3) The GL-03 section has limited aquifer potential, with low to moderate resistivity values of 1.61–357 Ω·m at depths of approximately 22.5–56 meters. This indicates that it is predominantly composed of water-saturated clay and loose sand capable of storing groundwater.
4) The results of the geoelectric interpretation are in line with the Hydrogeological Map of Kolaka Regency which shows the category of aquifer zones with flow through intergranular spaces (moderately productive aquifers with wide distribution), as well as aquifers with flow through fracture spaces and channels (locally, productive aquifers).
5) The geoelectric interpretation is also consistent with the Regional Geological Map of the Kolaka Sheet. Low-moderate resistivity corresponds to the Buara Formation (QI) and alluvium (Qa), while high resistivity describes the impermeable chalcerenite, coral limestone, sandstone, and marl of the Eemoiko Formation (Tmpe) which are aquitards.

The results of this study provide important practical implications for groundwater resource development in Watubangga District. Based on the geoelectrical interpretation, the GL-02 and GL-01 survey lines are recommended as priority locations for groundwater drilling due to their extensive lateral aquifer continuity and relatively low resistivity values indicating productive water-bearing formations. The recommended target depth for groundwater extraction ranges from approximately 20 m to 70 m, where the most significant aquifer zones were identified. In addition, further studies involving three-dimensional (3D) geoelectrical surveys, pumping tests, and groundwater quality analysis are recommended to improve the accuracy of aquifer characterization and support sustainable groundwater management in the Watubangga area.

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