Integrated geoelectrical and physicochemical characterization of groundwater and aquifer potential in volcanic aquifer systems of Central Java, Indonesia

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Abstract
Groundwater constitutes a strategic freshwater resource that is increasingly important for sustaining domestic, institutional, agricultural, and industrial activities, particularly in volcanic regions where surface water availability is often limited. This study aimed to evaluate groundwater quality and delineate aquifer potential in volcanic terrains of Central Java, Indonesia, through an integrated geoelectrical and physicochemical approach. Two-dimensional electrical resistivity surveys were conducted at the Klaten and Karanganyar campuses of UIN Raden Mas Said Surakarta using the Wenner configuration to characterize subsurface lithology and identify potential aquifer zones. Groundwater samples were collected from existing wells and analyzed for physical, chemical, and microbiological parameters in accordance with the Indonesian Ministry of Health Regulation No. 2 of 2023. The geoelectrical interpretation revealed that both study areas are dominated by volcanic deposits consisting of tuff, breccia, and lava. In Karanganyar, the prospective aquifer is characterized by interbedded tuffaceous sand occurring at depths of approximately 47–127 m, whereas in Klaten the aquifer comprises interbedded tuffaceous sand and fine sand at depths of 27–100 m. Groundwater quality analysis showed that most physical, chemical, and microbiological parameters complied with drinking water standards. However, nitrate concentration in Karanganyar groundwater (22.37 mg/L) exceeded the permissible limit, and total coliform bacteria were detected at 2 CFU/100 mL, indicating localized anthropogenic contamination. Overall, the integrated hydro geophysical and water quality assessment demonstrated that both sites possess moderate-to-high groundwater potential, although water treatment and regular monitoring are recommended to ensure sustainable and safe groundwater utilization.

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1. Introduction

Groundwater constitutes a vital freshwater resource stored within the unsaturated (vadose) and saturated (phreatic) zones of soil and geological formations. Its occurrence, recharge, and movement are controlled by fundamental hydrological processes, including precipitation, evapotranspiration, and interactions between surface water and subsurface systems. Rainfall infiltrates the soil profile, percolates through the vadose zone, and recharges aquifers in the saturated zone. Groundwater subsequently flows under hydraulic gradients through interconnected pore spaces and fractures, eventually discharging into rivers, low-lying terrains, springs, or coastal environments (Freeze & Cherry, 2017; Gleeson et al., 2020). As a renewable natural resource, groundwater plays a crucial role in meeting human water demands while simultaneously contributing to socioeconomic development and ecosystem sustainability. It is widely utilized for domestic consumption, agriculture, industry, and other strategic purposes. In Indonesia, groundwater management is regulated through an integrated and environmentally sound framework based on hydrogeological boundaries, emphasizing basin-scale governance to ensure long-term resource sustainability (Nugroho et al., 2020; Ministry of Public Works and Housing, 2021).

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In volcanic terrains, hydrogeological investigations aimed at identifying groundwater potential are inherently complex due to heterogeneous lithology and concealed subsurface conditions. Recharge pathways, storage zones, and groundwater flow systems are not directly observable, necessitating the application of geophysical methods to characterize aquifer systems (Loke et al., 2020; Singha & Gorelick, 2021). Consequently, groundwater potential assessment generally focuses on two key aspects: (1) characterization of aquifer materials, including lithological and hydrostratigraphic units that control porosity and transmissivity, and (2) evaluation of groundwater as a mobile fluid occupying pore spaces and fracture networks within these formations. During extended dry seasons, groundwater scarcity frequently emerges as a critical issue, particularly in regions reliant on subsurface water resources. One effective mitigation strategy involves identifying hydrogeologically favorable zones for borehole drilling. This process requires comprehensive subsurface information, including lithology, spatial distribution, aquifer depth, and saturated thickness. Such data are commonly obtained through hydrogeophysical surveys, with electrical resistivity methods widely employed for aquifer delineation and groundwater exploration (Chambers et al., 2019; Loke et al., 2020).

Electrical resistivity techniques have proven to be effective and reliable tools for subsurface characterization. By measuring the electrical response of subsurface materials under natural conditions or controlled current injection, these methods enable the interpretation of geological structures, stratigraphic layering, and hydrogeological conditions (Binley & Slater, 2020). Resistivity surveys facilitate the identification of aquifer boundaries, estimation of saturated thickness, and delineation of potential groundwater-bearing zones, thereby supporting informed decision-making in groundwater resource development and management. Aquifer identification further aims to locate subsurface units with sufficient secondary permeability capable of yielding groundwater of adequate quality and quantity. This approach is essential for selecting optimal drilling targets and ensuring sustainable groundwater abstraction to meet potable water demands. Accordingly, aquifer delineation represents a fundamental step in well siting and long-term groundwater resource planning (Li et al., 2021; Gleeson et al., 2020).

The global demand for clean and reliable water supplies continues to increase in response to population growth and socioeconomic development. Ensuring the availability of freshwater in both sufficient quantity and acceptable quality has therefore become a critical priority. In this context, groundwater development offers substantial potential as a sustainable source of clean water, supporting the needs of academic institutions as well as surrounding communities (Boimau et al., 2018; UN-Water, 2023). Despite the widespread application of electrical resistivity methods for groundwater exploration in volcanic environments, previous studies have predominantly focused on aquifer delineation and subsurface lithological characterization. Comparatively fewer studies have integrated hydrogeophysical investigations with comprehensive groundwater quality assessments, particularly in volcanic aquifer systems of Central Java, Indonesia. As a result, the linkage between aquifer potential, hydrogeological conditions, and groundwater quality remains inadequately understood. Moreover, site-specific information regarding groundwater availability and quality in the volcanic terrains of Klaten and Karanganyar Regencies is limited. Therefore, this study integrates two-dimensional electrical resistivity tomography and physicochemical–microbiological groundwater analyses to characterize aquifer systems, evaluate groundwater quality, and identify suitable zones for sustainable groundwater development.

2. Method

The geoelectrical survey locations were selected based on hydrogeological, practical, and institutional considerations. Both study sites are located within the UIN Raden Mas Said Surakarta campuses, where increasing water demand necessitates the identification of sustainable groundwater resources. The Klaten site is situated within the Merapi volcanic aquifer system, whereas the Karanganyar site is located within the Lawu volcanic aquifer system, allowing a comparative assessment of aquifer characteristics under different volcanic geological settings. In addition, previous hydrogeological information for both locations was limited, creating a need for detailed subsurface investigation to support groundwater resource development. The selected survey lines were positioned in open and accessible areas that permitted optimal electrode deployment and were representative of locations proposed for future groundwater abstraction. This site-selection strategy enabled the acquisition of geoelectrical and hydrogeological data relevant to both scientific investigation and groundwater management planning.

2.1. Two-Dimensional Electrical Resistivity Method

The electrical resistivity method is founded on the principle that when a direct current is introduced into a medium, the ratio of the measured electrical potential difference (V) to the injected current (I) remains constant for that medium. Martiel Geophysics Model Resistivity Meter in this study was shown in Figure 1.

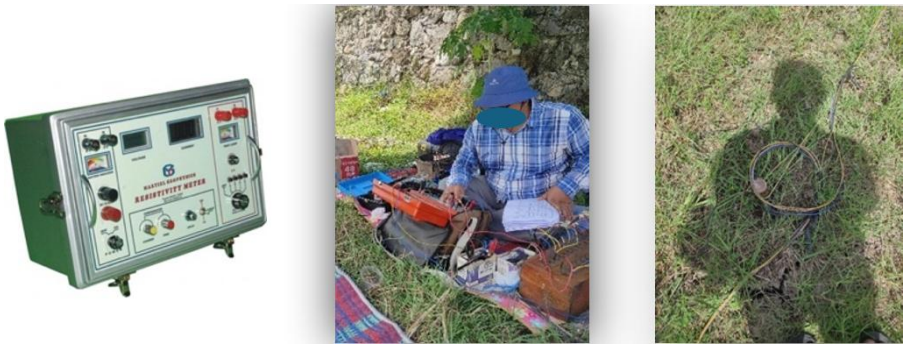

Figure 1. Martiel Geophysics Model Resistivity Meter

The value of this constant is governed by the intrinsic properties of the material and is defined as electrical resistance (R), which can be expressed mathematically as: Electrical resistivity (ρ) is expressed as: $\rho = R \times K$ ($\Omega \cdot m$) ; where K represents the geometric factor. For the Wenner electrode configuration, the geometric factor is defined as $K = 2\pi a$, with a denoting the electrode spacing. The Wenner electrode arrangement fundamentally consists of two current electrodes and two potential electrodes aligned linearly with equal spacing. An illustration of the two-dimensional data acquisition configuration is presented in Figure 2.

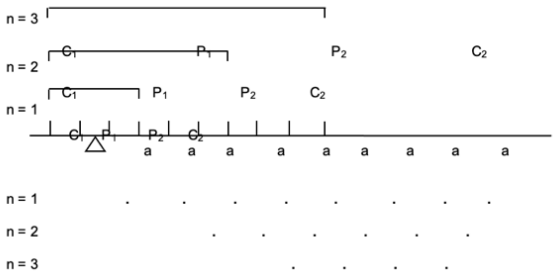

Figure 2. The two-dimensional data acquisition configuration

Field data acquisition was conducted along a two-dimensional survey line with a total length of 360-720 m and an investigation depth reaching approximately 120 m. The spacing between measurement points was set at 20 m, resulting in a total of 12 pseudo-depth layers.

2.2. Physicochemical and Microbiological Water Quality Assessment

Groundwater samples collected from two campus locations in Klaten and Karanganyar Regencies were analyzed to assess their water quality characteristics. Statistical analyses were performed using IBM SPSS Statistics software. Differences between groundwater quality parameters at the Klaten and Karanganyar sites were evaluated using the appropriate statistical test at a 95% confidence level, with statistical significance defined as $p < 0.05$. For groundwater quality assessment, water samples were collected from existing groundwater sources at both study sites and analyzed for physical (temperature, TDS, turbidity, color, odor), chemical (pH, nitrate, nitrite, fluoride, heavy metals), and microbiological (Escherichia coli and total coliform) parameters in accordance with national drinking water quality standards conducted in accordance with the Indonesian Ministry of Health Regulation Number 2 of 2023.

3. Results and Discussion

3.1. Groundwater Exploration

Groundwater exploration at the South Ring Road area of Karanganyar, Dukuh Ngaliyan, Lalung Subdistrict, Karanganyar District, Karanganyar Regency, was conducted using a two-dimensional electrical resistivity method. A single 2D survey line was acquired with a total length of 720 m and an investigation depth reaching approximately 120 m. The study area is predominantly underlain by Lawu Volcanic Rocks (Qa), consisting of volcanic breccia, lava, and tuff. The aquifer system is classified as highly productive, with extensive lateral distribution and highly variable continuity. The recommended drilling location may be adjusted to align with the planned borehole position within the Karanganyar Regency Government land area. Drilling at the recommended site may be carried out to a depth of 100 m, with a well construction depth of 99 m is presented in Figure 3.

The geoelectrical survey results reveal significant hydrogeological differences between the Karanganyar and Klaten sites despite both being located within volcanic terrains of Central Java. In Karanganyar, the subsurface is dominated by Lawu Volcanic Rocks and is characterized by a deeper aquifer system occurring at approximately 47–127 m depth. The interpreted aquifer consists predominantly of interbedded tuffaceous sand layers with extensive lateral distribution, suggesting favorable groundwater storage capacity. The greater investigation depth (approximately 120 m) and broader survey coverage (720 m) indicate that the aquifer extends continuously across a substantial portion of the study area, supporting its classification as a highly productive aquifer system. Similar studies have demonstrated that volcanic stratigraphy and depositional facies strongly influence aquifer continuity, groundwater storage, and flow behavior in volcanic terrains (Marcelli et al., 2023; Poncela et al., 2022). These characteristics make the site suitable for long-term groundwater abstraction to support institutional and public water demand.

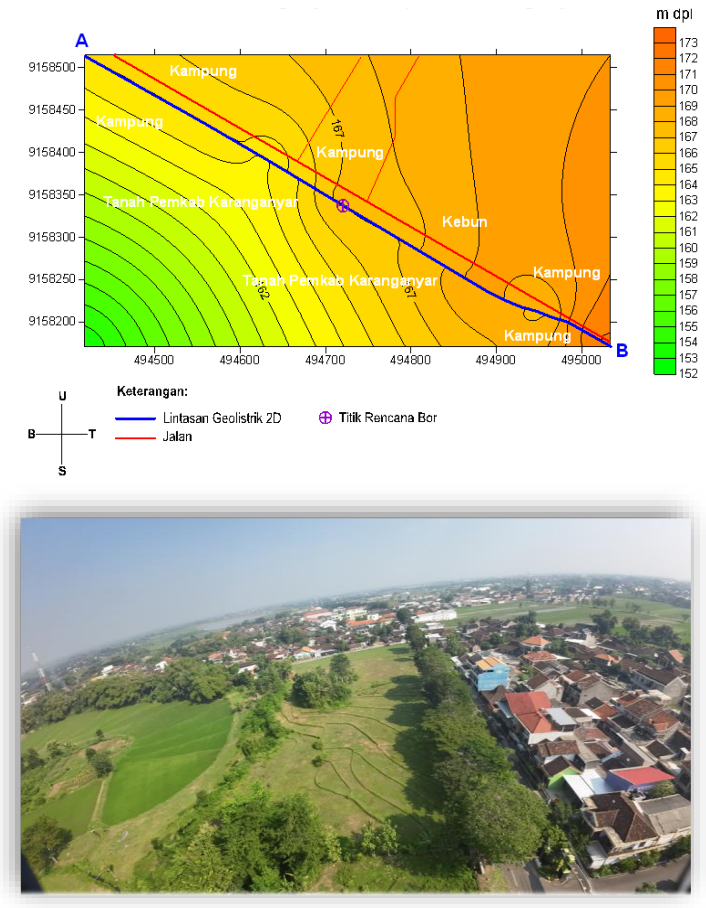

Figure 3. Groundwater Exploration at UIN Raden Mas Said Surakarta-Karanganyar Campus

Groundwater exploration at Jalan Pakis Daleman, Wadunggetas Village, Wonosari District, Klaten Regency, was conducted using a two-dimensional electrical resistivity method. A single 2D survey line was acquired with a total length of 360 m, providing an interpreted investigation depth of up to 100 m. The exploration area is predominantly underlain by Merapi Volcanic Rocks (Qvm), composed of volcanic breccia, lava, and tuff. The aquifer system is classified as productive, with extensive lateral distribution and moderate continuity. The recommended drilling location may be adjusted to correspond with the planned borehole position, specifically within the Campus II area of UIN Raden Mas Said Surakarta. Drilling at the recommended site may be conducted to a depth of 100 m, with a well construction depth of 99 m was shown in Figure 4.

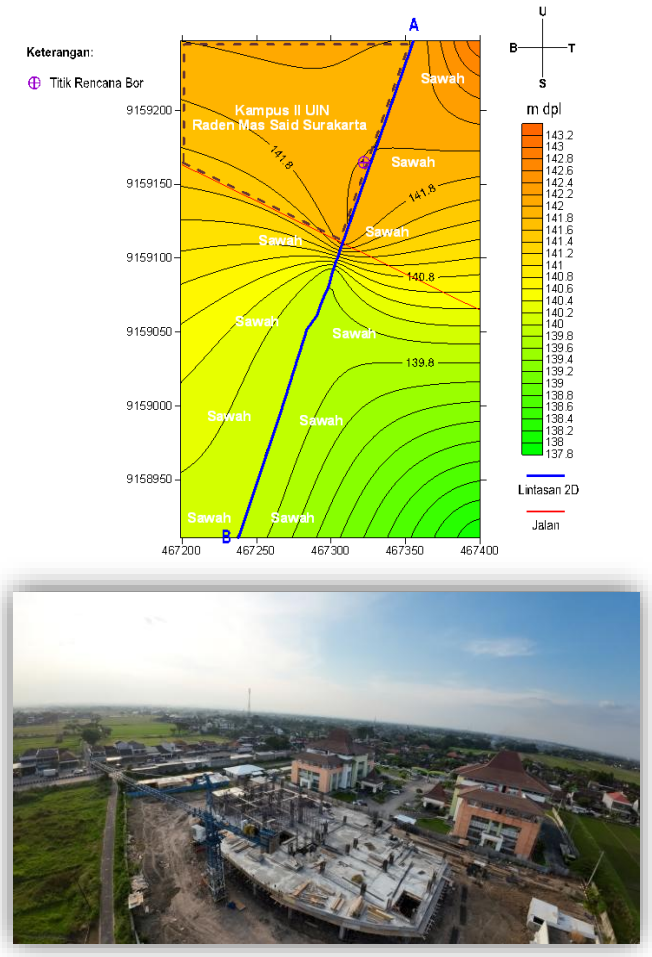

Figure 4. Groundwater Exploration at UIN Raden Mas Said Surakarta-Klaten Campus

In contrast, the Klaten site, which is underlain by Merapi Volcanic Deposits, exhibits a relatively shallower aquifer system occurring between 27 and 100 m depth. The aquifer is characterized by interbedded tuffaceous sand and fine sand layers, indicating higher sediment heterogeneity than that observed in Karanganyar. Although the aquifer demonstrates good groundwater potential and extensive lateral distribution, its continuity is interpreted to be more moderate. Consequently, while both sites are expected to provide similar well yields (5–10 L/s), the Karanganyar aquifer appears to possess greater storage potential and continuity, whereas the Klaten aquifer may be more susceptible to local variations in lithology and recharge conditions. These findings highlight the importance of considering local volcanic depositional environments when planning groundwater development strategies in Central Java, as groundwater occurrence and hydrochemical evolution are strongly controlled by the complexity of multilayer volcanic aquifer systems (Madrigal-Solís et al., 2022).

3.2. Hydrogeological Characterization

The subsurface conditions beneath the Karanganyar campus (Figure 5), interpreted along a two-dimensional geoelectrical resistivity profile, indicate the presence of volcanic lithological units dominated by tuff, breccia, and lava. The resistivity distribution reflects variations in lithology, grain size, and water content, which are critical for aquifer identification. Tuffaceous clay exhibits low resistivity values ranging from 0.1 to 10 Ωm, indicating fine-grained material with high clay content and limited permeability. Interbedded tuffaceous clay and tuffaceous sand show slightly higher resistivity values (10–20 Ωm), suggesting mixed lithology with moderate water retention but restricted groundwater flow. Layers dominated by tuffaceous sand interbedded with tuffaceous clay display resistivity values of 20–30 Ωm, while relatively clean tuffaceous sand presents resistivity values ranging from 30 to 50 Ωm. These resistivity ranges are commonly associated with moderately permeable volcanic aquifers (Reynolds, 2011; Li et al., 2021). Higher resistivity values correspond to coarser and more consolidated volcanic materials. Tuffaceous sand interbedded with breccia exhibits resistivity values between 50 and 100 Ωm, while volcanic breccia ranges from 100 to 150 Ωm. The highest resistivity values (150–300 Ωm) are interpreted as breccia interbedded with lava, representing compact and massive volcanic units with low primary porosity and limited groundwater potential (Loke et al., 2020; Singha & Gorelick, 2021).

The subsurface beneath the Klaten campus (Figure 5), as interpreted from a two-dimensional electrical resistivity survey, is predominantly composed of volcanic formations, namely tuff, breccia, and lava. Spatial variations in resistivity values indicate differences in lithological composition, particle size distribution, consolidation degree, and groundwater saturation, which collectively govern the hydrogeological behavior of the subsurface system. Tuffaceous clay is associated with very low resistivity values (0.1–10 Ωm), reflecting fine-grained material with high clay content and poor permeability. Resistivity values of 10–20 Ωm are attributed to interbedded tuffaceous clay and tuffaceous sand, indicating heterogeneous units with limited groundwater transmissivity. Layers consisting of tuffaceous sand intercalated with tuffaceous clay exhibit resistivity values of 20–30 Ωm, whereas relatively well-sorted tuffaceous sand shows higher resistivity values of 30–50 Ωm. These resistivity characteristics are typical of moderately permeable volcanic aquifers capable of groundwater storage and flow (Loke et al., 2020; Li et al., 2021). Increasing resistivity values correspond to coarser and more consolidated volcanic deposits, including tuffaceous sand interbedded with breccia (50–100 Ωm) and volcanic breccia (100–150 Ωm). The highest resistivity range (150–300 Ωm) is interpreted as breccia interbedded with lava, representing dense volcanic units with low primary porosity and limited groundwater potential (Singha & Gorelick, 2021).

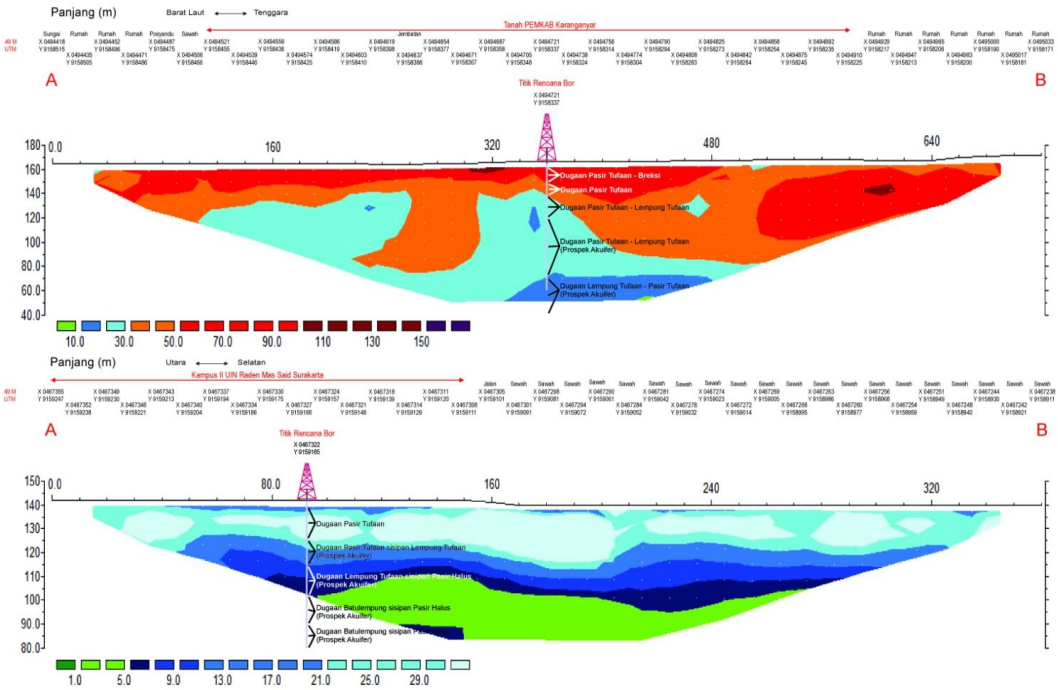

Figure 5. Hydrogeological Characteric of Karanganyar Campus (above) and Klaten Campus (below)

Although both study sites are developed within volcanic terrains composed of tuff, breccia, and lava units, the geoelectrical interpretation reveals notable differences in aquifer architecture and groundwater potential. The Karanganyar site, located within the Lawu volcanic deposits, is characterized by a deeper aquifer system occurring at approximately 47–127 m depth and dominated by laterally continuous tuffaceous sand layers. The greater depth and continuity of these permeable units suggest a larger groundwater storage capacity and a more productive aquifer system. In contrast, the Klaten site, which is underlain by Merapi volcanic deposits, contains a shallower aquifer system at depths of approximately 27–100 m and is characterized by alternating tuffaceous sand and fine sand layers. This lithological heterogeneity indicates more variable hydrogeological conditions and potentially lower aquifer continuity.

Despite these differences, both sites exhibit favorable groundwater prospects with estimated well yields of 5–10 L/s and recommended drilling depths of approximately 100 m. However, the Karanganyar aquifer appears to offer greater storage potential and long-term groundwater availability, whereas the Klaten aquifer may be more sensitive to local lithological variations and recharge dynamics. These findings demonstrate that local volcanic depositional processes exert a significant influence on aquifer geometry, continuity, and groundwater resource potential, underscoring the importance of site-specific hydrogeological assessment for groundwater development planning. Both well areas yield of 5–10 L/s should be considered a preliminary hydrogeological prediction based on the interpreted aquifer thickness, lithological composition, and lateral continuity derived from the geoelectrical survey. The presence of extensive tuffaceous sand layers suggests favorable porosity and permeability conditions that may support moderate groundwater production. However, geoelectrical data alone cannot directly quantify aquifer hydraulic properties or sustainable pumping rates because geophysical measurements provide indirect information on subsurface characteristics rather than

direct measurements of hydrogeological parameters (Binley et al., 2015). Therefore, the estimated yield requires further validation through exploratory drilling, borehole lithological logging, step-drawdown tests, and constant-rate pumping tests to determine aquifer transmissivity, storage characteristics, and long-term groundwater productivity. Consequently, the reported yield range should be regarded as an initial estimate rather than a confirmed production capacity.

3.3. Groundwater Characteristic

The physical characteristics of groundwater from Karanganyar and Klaten Regencies (was shown in Table 1) indicated good overall quality. Water temperature ranged from 27.3 to 27.4 °C, complying with the permissible deviation of ±3 °C from ambient air temperature, suggesting minimal thermal disturbance and stable hydrogeological conditions (WHO, 2022). Total Dissolved Solids (TDS) concentrations were 247 mg/L in Karanganyar and 211 mg/L in Klaten, both well below the maximum permissible limit of 300 mg/L, indicating low mineralization and acceptable palatability for domestic use (Ministry of Health of the Republic of Indonesia, 2023). Low turbidity values (0.4–0.5 NTU), low color intensity (1–4 TCU), and the absence of unusual odor further confirmed that the groundwater samples were physically clear and free from excessive suspended solids or organic matter. Such physical conditions are typical of protected aquifers and indicate limited surface water intrusion (Li et al., 2021).

Groundwater chemical properties (Table 1) showed that pH values ranged from 6.8 to 7.0, falling within the recommended range of 6.5–8.5. Neutral pH conditions are favorable because they reduce corrosion potential and limit the mobilization of heavy metals in groundwater systems (WHO, 2022; Giri & Singh, 2019; Kumar et al., 2021). Nitrate concentration in Karanganyar groundwater reached 22.37 mg/L, exceeding the maximum permissible limit of 20 mg/L, while Klaten groundwater remained within acceptable limits at 15.56 mg/L. Elevated nitrate levels in groundwater are widely associated with anthropogenic activities, particularly agricultural fertilizer application and leaching from on-site sanitation systems (Ward et al., 2021; Shalyari et al., 2022; Zhai et al., 2021). This finding indicates localized contamination pressure in Karanganyar Regency and reflects the influence of land-use practices on groundwater quality. Nitrite concentrations in both locations were below detection limits (<0.0314 mg/L), indicating the absence of acute nitrogen pollution and effective oxidation of nitrite to nitrate within the aquifer system. Similar conditions have been reported in groundwater systems dominated by aerobic environments (Li et al., 2021). Heavy metals, including hexavalent chromium (Cr^{6+}), iron (Fe), manganese (Mn), arsenic (As), cadmium (Cd), lead (Pb), and aluminum (Al), were detected at concentrations far below regulatory thresholds, suggesting minimal geogenic release or industrial contamination and reflecting favorable hydrochemical conditions of the aquifers (Rahman et al., 2020). Fluoride concentrations ranged from 0.24 to 0.32 mg/L, remaining within safe limits and consistent with values considered beneficial for dental health without posing a risk of fluorosis (WHO, 2022). Residual free chlorine was not detected (<0.03 mg/L) in both groundwater samples, which is typical for untreated groundwater sources; however, the absence of residual disinfectant indicates that the water cannot be considered microbiologically safe for direct consumption without further treatment (Ministry of Health of the Republic of Indonesia, 2023).

Table 1. The Characteristics of Groundwater from Karanganyar and Klaten Regencies-UIN Raden Mas Said Surakarta Campus

Parameter	Maximum Permissible Level*	Karanganyar Groundwater	Klaten Groundwater
A. Physical			
Temperature	within ±3 °C of ambient air temperature	27.4	27.3
Total Dissolved Solids (TDS)	< 300 mg/L	247	211
Turbidity	< 3 NTU	0.5	0.4
Color	≤ 10 TCU	4	1
Odor	no unusual odor	no unusual odor	no unusual odor
B. Chemical			
pH	6.5 – 8.5	7.0	6.8
Nitrate (as NO_3)	≤ 20 mg/L	22.37	15.56
Nitrite (as NO_2)	≤ 3 mg/L	< 0.0314	< 0.0314
Hexavalent Chromium (Cr^{6+})	≤ 0.01 mg/L	< 0.0066	< 0.0066
Dissolved Iron (Fe)	≤ 0.2 mg/L	< 0.0168	< 0.0168
Dissolved Manganese (Mn)	≤ 0.1 mg/L	< 0.0098	< 0.0098
Residual Chlorine (free)	0.2 – 0.5 mg/L (with 30-minute contact time)	< 0.03	< 0.03
Arsenic (As)	≤ 0.01 mg/L	< 0.005	< 0.005
Cadmium (Cd)	≤ 0.003 mg/L	< 0.0009	< 0.0009
Lead (Pb)	≤ 0.01 mg/L	< 0.0011	< 0.0011
Fluoride (F)	≤ 1.5 mg/L	0.3223	0.2442
Aluminium (Al)	≤ 0.2 mg/L	< 0.0086	0.0392

Parameter	Maximum Permissible Level*	Karanganyar Groundwater	Klaten Groundwater
C. Microbiological			
Escherichia coli (*E. coli*)	0 CFU/100 mL	0	0
Total Coliform	0 CFU/100 mL	2	0

*Maximum Permissible Level: Ministry of Health of the Republic of Indonesia (2023)

Microbiological analysis (Table 1) showed that Escherichia coli was not detected in either groundwater sample, indicating no direct fecal contamination at the time of sampling. However, total coliform bacteria were detected in Karanganyar groundwater at 2 CFU/100 mL, exceeding the permissible limit of 0 CFU/100 mL. The presence of total coliforms is commonly used as an indicator of environmental contamination and suggests vulnerability of the water source to surface infiltration or inadequate sanitation infrastructure (Bain et al., 2021; Genter et al., 2023). Similar patterns of microbial contamination have been reported in Indonesian groundwater influenced by topographic and sanitation conditions (Indrastuti et al., 2021), and in rapidly urbanizing regions where total coliform and E. coli were prevalent in boreholes and wells (Bekoe et al., 2025). Although total coliforms are not necessarily pathogenic, they increase the likelihood of pathogen intrusion under unfavorable conditions such as rainfall events (Efstratiou et al., 2022), and seasonal dynamics can affect E. coli detection rates (Kintari & Priadi, 2024). Additionally, both internal and external factors have been shown to significantly influence coliform levels in groundwater (Diinii et al., 2023).

The groundwater chemistry of both study sites reflects the influence of volcanic aquifer materials and local recharge conditions. Relatively low TDS concentrations (211–247 mg/L) indicate weak mineralization and limited water–rock interaction, suggesting that groundwater recharge is relatively recent and that groundwater circulation occurs predominantly through permeable volcanic deposits. The near-neutral pH values (6.8–7.0) further support geochemical equilibrium between groundwater and volcanic minerals, while also limiting the mobility of trace metals. The consistently low concentrations of Fe, Mn, As, Cd, Pb, Cr^{6+}, and Al indicate minimal geogenic metal release and suggest that the volcanic aquifers have not undergone intensive geochemical weathering or contamination from industrial sources. Fluoride concentrations below 0.5 mg/L are characteristic of volcanic aquifers with limited fluoride-bearing mineral dissolution and relatively short groundwater residence times. Despite the overall favourable hadrochemical condition, distinct differences were observed between the two sites. Karanganyar groundwater exhibited higher TDS and nitrate concentrations than Klaten groundwater, indicating a stronger influence of surface-derived inputs. The nitrate concentration exceeding the drinking water guideline suggests that agricultural fertilization, domestic wastewater seepage, or other anthropogenic activities may contribute nitrogen to the aquifer through recharge pathways. This interpretation is further supported by the detection of total coliform bacteria in Karanganyar groundwater, which indicates partial vulnerability of the aquifer to surface infiltration. In contrast, the absence of total coliforms and lower nitrate concentrations in Klaten groundwater suggest a better-protected aquifer system and reduced influence of anthropogenic contamination. These findings indicate that groundwater quality in both areas is controlled not only by volcanic lithology but also by differences in land use, recharge processes, and aquifer protection conditions. Consequently, groundwater development strategies should incorporate both hydrogeological and land-use considerations to ensure long-term water quality sustainability.

4. Conclusion

The integration of two-dimensional electrical resistivity surveying and groundwater quality assessment provided a comprehensive evaluation of volcanic aquifer systems in Klaten and Karanganyar, Central Java. Geoelectrical investigations identified productive aquifer zones associated with interbedded tuffaceous sand and fine sand, occurring at depths of 47–127 m in Karanganyar and 27–100 m in Klaten, with estimated well yields of 5–10 L/s. The deeper and more laterally continuous aquifer in Karanganyar suggests greater groundwater storage potential than the relatively shallower and more heterogeneous aquifer system in Klaten, while groundwater quality at both sites was generally favorable. However, elevated nitrate concentration (22.37 mg/L) and detectable total coliform contamination (2 CFU/100 mL) in Karanganyar groundwater suggest anthropogenic influences and increased aquifer vulnerability. In contrast, Klaten groundwater exhibited lower nitrate levels and no microbiological contamination. These findings demonstrate the importance of integrating geophysical and groundwater quality assessments for groundwater exploration and management. The results provide a scientific basis for sustainable groundwater development, while future studies should incorporate drilling verification, pumping tests, and long-term hydrogeochemical monitoring to evaluate aquifer sustainability and contamination risks.

Author Contributions

Ronnawan Juniatmoko: Conceptualization, Methodology, Validation. Sadewa Aziz Diamonda: Data curation, Graphic Visualization, Writing - Original draft preparation. Dwi Purbowati: Investigation, Writing - Reviewing and Editing. Rega Ferdinan Syaputro: Software, Drone-Camera Visualization.

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Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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