

Estimation of Sustained Groundwater Resource Potential by Analyzing Aquifer Depth Lithology in Selebar Subdistrict, Bengkulu

Fadilah^{1,2*}, Marulak Simarmata³, Muchammad Farid⁴, Sukisno⁵

¹Doctoral Program of Natural Resources and Environmental Management, Faculty of Agriculture, University of Bengkulu, Bengkulu, Indonesia

²Natural Science Tadris Study Program, Faculty of Tarbiyah and Tadris, Fatmawati Sukarno Bengkulu State Islamic University, Bengkulu, Indonesia

³Department of Crop Production, Faculty of Agriculture, University of Bengkulu, Bengkulu, Indonesia

⁴Department of Physics, Faculty of Mathematics and Natural Science, University of Bengkulu, Bengkulu, Indonesia

⁵Department of Soil Science, Faculty of Agriculture, University of Bengkulu, Bengkulu, Indonesia

Received: August 30, 2025

Revised: November 15, 2025

Accepted: November 29, 2025

Published: November 30, 2025

Corresponding Author:

Fadilah

fadilah@mail.uinfasbengkulu.ac.id

DOI: [10.29303/jppipa.v11i11.12799](https://doi.org/10.29303/jppipa.v11i11.12799)

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Abstract: Rapid urban development frequently overlooks groundwater availability, potentially causing environmental degradation and unsustainable resource management. This study aims to determine groundwater potential through geoelectric resistivity analysis in Selebar Subdistrict, Bengkulu, specifically at Fatmawati Sukarno State Islamic University campus area. The Schlumberger configuration method was employed across four measurement tracks, with electrode spacing systematically varied to detect subsurface resistivity variations at depths up to 300 meters. Data were processed using Progress Version 3.0 software, applying both direct and indirect interpretation methods through inversion techniques. Laboratory analysis of water samples assessed physical and chemical parameters including pH, turbidity, Total Dissolved Solids (TDS), color, odor, and temperature against Minister of Health Regulation No. 32/2017 standards. Results identified two distinct aquifer systems: an unconfined aquifer at 9.94-25.53 meters depth with 15.59 meters thickness, and a confined aquifer exceeding 161.43 meters depth. Resistivity values ranged from 0.93 to 6.74 ohm-m, indicating water-bearing clayey sandstone formations. Water quality analysis demonstrated that samples from three locations met drinking water standards, while the Student Center location exhibited elevated pH (8.64), rendering it unsuitable for direct consumption but acceptable for non-potable applications.

Keywords: Aquifer; Groundwater; Resistivity; Sandstone; Sustainable.

Introduction

Water constitutes the fundamental resource for sustaining life across all biological systems, including human populations, fauna, and flora. Its multifunctional significance encompasses domestic consumption, sanitation infrastructure, hygiene maintenance, and industrial production processes (Ajayi et al, 2022). The heterogeneous distribution of water resources across terrestrial surfaces necessitates

judicious utilization strategies to ensure long-term sustainability and intergenerational resource security.

Indonesia, characterized as an archipelagic nation with extensive maritime territories, demonstrates significant hydrological complexity. According to the National Coordinating Agency for Surveys and Mapping (2023), approximately 97% of total water resources comprise saline oceanic waters, while merely 3% constitutes freshwater reserves distributed among fluvial systems, lacustrine environments, surface water

How to Cite:

Fadilah, F., Simarmata, M., Farid, M., & Sukisno, S. (2025). Estimation of Sustained Groundwater Resource Potential by Analyzing Aquifer Depth Lithology in Selebar Subdistrict, Bengkulu. *Jurnal Penelitian Pendidikan IPA*, 11(11), 1143-1150. <https://doi.org/10.29303/jppipa.v11i11.12799>

bodies, and subsurface aquifers. Among these freshwater sources, groundwater represents the optimal resource for potable water supply due to its natural filtration processes and relative protection from surface contamination.

Contemporary urbanization patterns frequently exhibit inadequate consideration of groundwater resource sustainability, potentially precipitating critical environmental consequences. The transformation of Institut Agama Islam Negeri (IAIN) Bengkulu to Universitas Islam Negeri (UIN) Fatmawati Sukarno Bengkulu, mandated through Presidential Regulation Number 45 of 2021, has catalyzed accelerated infrastructure development and demographic intensification within the Selebar Subdistrict. This institutional elevation has generated substantial increases in academic activities, administrative operations, and ancillary commercial establishments, including student accommodation facilities and micro-enterprise development. The consequent anthropogenic pressure on groundwater resources, coupled with limited hydrogeological data availability, creates significant risks of resource depletion, aquifer contamination, and hydrological system degradation.

Previous investigations utilizing geophysical methods for groundwater exploration have demonstrated the efficacy of electrical resistivity techniques in aquifer characterization (Ahmed et al., 2022; Alarifi et al., 2022; Tahera-Tun-Humayra et al., 2025). However, comprehensive studies integrating geoelectric resistivity mapping with detailed water quality assessment in rapidly developing urban-academic environments remain limited, particularly within the Bengkulu regional context. The novelty of this research lies in its integrated approach, combining Schlumberger configuration geoelectric surveys with systematic laboratory analysis to establish a comprehensive groundwater resource assessment framework specifically tailored for academic institution planning.

Therefore, this study aims to determine subsurface resistivity values and aquifer depth characteristics as essential references for sustainable groundwater extraction planning. The research objectives encompass: (1) identifying and mapping groundwater-bearing lithological formations through geoelectric resistivity analysis; (2) determining optimal drilling depths for aquifer exploitation; and (3) assessing groundwater quality parameters against established regulatory standards. The urgency of this investigation is underscored by the imperative to establish evidence-based groundwater management protocols that can support sustainable campus development while preserving hydrological ecosystem integrity for future generations.

Method

Research Design and Survey Planning

Prior to field investigation, comprehensive survey design protocols were established to ensure methodological rigor and environmental responsibility. Site selection criteria incorporated accessibility considerations, minimal disruption to residential activities and agricultural operations, and adherence to environmental protection principles. Following established hydrogeological guidelines (Asra, 2012), measurement locations were positioned within one kilometer of potential water utilization sites to ensure practical applicability of findings.

Geoelectric Data Acquisition

Field data collection employed the active geophysical method of electrical resistivity surveying, specifically utilizing the Schlumberger electrode configuration. This configuration operates on the principle of injecting direct electrical current into the subsurface through two current electrodes (designated C1 and C2 or A and B) positioned symmetrically about a central measurement point, while simultaneously measuring the resulting potential difference through two potential electrodes (P1 and P2 or M and N) located at the survey center.

The Schlumberger configuration demonstrates superior performance in detecting lithological heterogeneity by systematically varying the current electrode spacing ($AB/2$) while maintaining constant potential electrode separation ($MN/2$). As the current electrode separation increases progressively, the electrical current penetrates deeper subsurface formations, enabling resistivity characterization at corresponding depths. The apparent resistivity (ρ_a) was calculated using the fundamental relationship:

$$\rho_a = K(\Delta V/I) \quad (1)$$

where K represents the geometric factor determined by electrode configuration, ΔV denotes the measured potential difference in volts, and I indicates the injected current in amperes. For the Schlumberger configuration, the geometric factor is expressed as:

$$K = \pi[(AB/2)^2 - (MN/2)^2]/(MN) \quad (2)$$

Field measurements were conducted across four distinct tracks within the UIN Fatmawati Sukarno Bengkulu campus area, with electrode spacings ranging from minimum separation to maximum penetration depths of approximately 300 meters. Environmental conditions during data acquisition, including

meteorological parameters and surface geology, were systematically documented to facilitate subsequent data interpretation.

Data Processing and Analysis

Acquired field data underwent systematic processing using Progress Version 3.0 geophysical interpretation software. Input parameters comprised measured AB/2 distances and corresponding apparent resistivity values. The software employed iterative inversion algorithms to resolve the one-dimensional subsurface resistivity structure, generating output parameters including individual layer thickness, cumulative depth, and true resistivity values for each identified stratigraphic unit.

Geological Interpretation

Resistivity data interpretation proceeded through integrated application of direct and indirect methodological approaches. Apparent resistivity values were plotted against electrode spacing on logarithmic coordinate systems to generate characteristic sounding curves. These field curves underwent comparative analysis with published theoretical master curves representing simplified geological models. Quantitative interpretation utilized established resistivity ranges for common geological materials (Telford et al., 1990), enabling lithological classification and aquifer identification. The interpretation methodology assumed horizontally stratified subsurface conditions with isotropic electrical properties within individual layers, consistent with standard geoelectric modeling conventions.

Water Quality Assessment

Following aquifer identification through geoelectric analysis, groundwater samples were extracted from accessible locations corresponding to identified water-bearing formations. Laboratory analysis encompassed comprehensive evaluation of physical and chemical parameters, including temperature measurement via calibrated thermometry, pH determination using electrometric methods, turbidity quantification through nephelometric techniques, Total Dissolved Solids (TDS) measurement, color assessment using platinum-cobalt standards, and organoleptic evaluation of odor characteristics. All analytical procedures adhered to standardized methodologies, with results evaluated against regulatory thresholds established in Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017 concerning Environmental Health Quality Standards and Water Health Requirements for Hygiene and Sanitation Purposes.

Results And Discussion

Geoelectric Resistivity Interpretation and Aquifer Characterization

The interpretation of geoelectric resistivity data employed a comprehensive analytical framework integrating both direct and indirect methodological approaches. Field-acquired apparent resistivity values, measured in ohm-meters (Ωm) across systematically varied electrode spacings, were plotted on double logarithmic coordinate systems to generate characteristic sounding curves. These empirical curves underwent comparative analysis with published theoretical master curves representing idealized multi-layer geological models, facilitating preliminary lithological interpretation. The apparent resistivity function, expressed mathematically as:

$$\rho_a = \rho_a f(AB/2d_1) \quad (3)$$

encapsulates comprehensive subsurface layer parameter information, where ρ_a represents first-layer resistivity, AB/2 denotes current electrode half-spacing, and d_1 indicates first layer thickness. Asymptotic curve behavior provides critical interpretive constraints: at large AB/2 values, the apparent resistivity curve converges toward the true resistivity of deepest penetrated formations, while at small AB/2 values, it approaches the resistivity of superficial layers.

The geoelectric resistivity method operates under fundamental assumptions validated for the study area: (1) the subsurface comprises discrete horizontal layers separated by planar boundaries exhibiting resistivity contrasts; (2) each stratigraphic unit possesses finite thickness except the lowermost layer which extends to infinite depth; (3) individual layers demonstrate homogeneous and isotropic electrical properties; (4) no natural electrical current sources exist beyond the artificially injected survey current; and (5) direct current injection ensures stable field conditions during measurement.

Lithological classification employed established resistivity-geology correlation principles (Telford et al., 1990), whereby specific resistivity ranges correspond to characteristic geological materials and hydrogeological conditions. Table 1 presents the standardized resistivity conversion framework utilized for geological interpretation, encompassing resistivity ranges from highly conductive materials ($0.001 \Omega\text{m}$ for pyrite) to highly resistive formations (exceeding $10^{13} \Omega\text{m}$ for rock salt and calcite).

Table 1. Resistivity-Lithology Correlation Standards for Geological Interpretation

Material	Resistivity Range (Ωm)
Pyrite	0.001-100
Groundwater	0.5-300
Clay	1.0-100
Sand	1-1,000
Shales	20-2,000
Sandstone	200-8,000
Alluvium	10-800
Gravel	100-600
Dry Gravel	600-10,000
Limestone	500-10,000
Basalt	200-100,000
Granite	200-100,000
Andesite	170-45,000
Quartz	500-800,000

Track 1: Former STQ Location Geoelectric Analysis

Geoelectric measurements along Track 1, extending approximately 150 meters through the former STQ (Seleksi Tilawatil Quran) venue within the UIN Fatmawati Sukarno Bengkulu campus (coordinates: S 03°49'91", E 102°19'90.6"), were conducted on June 8, 2024, under clear meteorological conditions. The interpreted subsurface profile revealed seven distinct geoelectric layers with progressively varying resistivity characteristics (Table 2).

Table 2. Stratigraphic Interpretation of Geoelectric Layers at Track 1

Layer	Depth Interval (m)	Thickness (m)	Resistivity (Ωm)	Lithological Interpretation
1	0.00-1.28	1.28	12.72	Overburden comprising alluvial deposits and unconsolidated sand
2	1.28-9.94	8.66	24.90	Coarse-grained sediments: sand with gravel and pebble inclusions
3	9.94-25.53	15.59	3.91	Saturated clayey sand (unconfined aquifer)
4	25.53-56.68	31.15	15.98	Moist clayey sand with potential brackish water influence
5	56.68-161.43	104.75	0.93	Water-saturated clayey sand formation
6	>161.43	Undefined	1.50	Confined aquifer: water-bearing sandstone and clay

The critical aquifer zones identified at Track 1 demonstrate dual-aquifer characteristics. The shallow unconfined aquifer, positioned between 9.94 and 25.53 meters depth with 15.59 meters thickness, exhibits resistivity of 3.91 Ωm , consistent with saturated fine-grained sediments. This resistivity value falls within the established range for groundwater-bearing clayey formations (0.5-300 Ωm for groundwater; 1-100 Ωm for clay), indicating substantial water saturation. The deeper confined aquifer, encountered at depths exceeding 161.43 meters with resistivity of 1.50 Ωm , represents a more protected water resource insulated by overlying impermeable clay layers. This interpretation aligns with established hydrogeological principles whereby confined aquifers demonstrate enhanced water quality due to prolonged natural filtration and reduced vulnerability to surface contamination (Konotio et al., 2024; Mohammed et al., 2023).

Water quality assessment of samples extracted from Track 1 vicinity (Table 3) demonstrated full compliance with regulatory standards established in Minister of Health Regulation 32/2017. Physical parameters included temperature (25°C), TDS (154 mg/L), turbidity (0.54 NTU), color (0.181 PtCo), absence of detectable odor, and pH (8.10), all falling within acceptable ranges for potable water applications.

Table 3. Physicochemical Analysis of Groundwater Sample from Track 1

Parameter	Measured Value	Regulatory Standard	Compliance Status
Temperature	25°C	20-25°C optimal	Compliant
TDS	154 mg/L	<500 mg/L	Compliant
Turbidity	0.54 NTU	<5 NTU	Compliant
Color	0.181 PtCo	<15 PtCo	Compliant
Odor	Odorless	Odorless	Compliant
pH	8.10	6.5-8.5	Compliant

Track 2: Alternative STQ Location Analysis

Geoelectric investigation along Track 2, conducted June 9, 2024 (coordinates: S 03°40'91", E 102°17'74.3"), revealed distinct subsurface characteristics compared to Track 1. The interpreted profile identified eight geoelectric layers, with the deepest water-bearing formation positioned at depths exceeding 70 meters, exhibiting resistivity of 6.74 Ωm (Table 4). This resistivity value, while elevated relative to Track 1's deeper aquifer, remains within the characteristic range for confined groundwater systems, suggesting compressed aquifer conditions with moderate water saturation.

Table 4. Geoelectric Layer Characteristics at Track 2

Layer	Depth Interval (m)	Resistivity (Ωm)	Lithological Interpretation
1	0.00–0.42	88.02	Surficial overburden and alluvium
2	0.42–4.24	20.18	Moist clayey sand
3	4.24–9.17	2.97	Shallow water-bearing clayey sand
4	9.17–22.68	4.42	Saturated clayey sediments
5	22.68–36.11	24.68	Weathered soil and clay mixture
6	36.11–59.95	18.47	Moist clayey sand
7	59.95–70.59	24.77	Clay-dominated weathered material
8	>70.59	6.74	Confined aquifer formation

Laboratory analysis of groundwater samples from Track 2 (Table 5) indicated compliance with potable water standards across all evaluated parameters, including temperature (25°C), TDS (168 mg/L), turbidity (0.57 NTU), color (0.245 PtCo), absence of odor, and pH (7.95). These results suggest that the deeper confined aquifer at this location maintains excellent water quality characteristics suitable for direct consumption applications.

Track 3: Library Location Hydrogeological Assessment

Geoelectric measurements at the campus library location, executed June 10, 2024 (coordinates: S 03°48'91", E 102°22'50.6"), revealed a seven-layer subsurface structure with notably high resistivity values in shallow formations. The presence of massive rock and gravel layers (resistivity values: 427.94 Ωm and 261.66 Ωm at depths 0.34–14.66 meters) indicates coarse-grained unconsolidated materials with minimal water content. The primary water-bearing formation, identified at 43.22–74.85 meters depth with resistivity of 1.30 Ωm and approximately 31 meters thickness, represents a substantial confined aquifer resource (Table 5).

Table 5. Subsurface Geoelectric Profile at Track 3 (Library)

Layer	Depth Interval (m)	Resistivity (Ωm)	Lithological Interpretation
1	0.00–0.34	64.81	Surficial alluvial deposits
2	0.34–4.75	427.94	Massive rock formations
3	4.75–14.66	261.66	Coarse gravel deposits
4	14.66–43.22	23.18	Mixed gravel, sand, and clay
5	43.22–74.85	1.30	Primary confined aquifer (31m thickness)
6	74.85–118.77	25.73	Soft mixed sediments
7	>118.77	105.39	Consolidated hard rock basement

The exceptionally low resistivity (1.30 Ωm) of the identified aquifer layer suggests high water saturation with elevated ionic content, potentially indicating brackish water characteristics influenced by proximity to wetland environments in the surrounding area. This interpretation necessitated comprehensive water quality assessment to determine potability.

Laboratory analysis (Table 7) revealed that while temperature (25°C), TDS (158 mg/L), color (0.277 PtCo), odor (absent), and pH (8.35) met regulatory standards, the turbidity value of 2.11 NTU exceeded the ideal threshold for drinking water (<1 NTU) established by WHO guidelines, though remaining below the maximum acceptable limit of 5 NTU. This elevated turbidity suggests the presence of suspended particulate matter, indicating that while the water is suitable for non-potable applications, pre-treatment filtration would be advisable for drinking water purposes.

Track 4: Student Center Location Evaluation

Geoelectric investigation at the Student Center vicinity, conducted June 11, 2024 (coordinates: S 03°27'91", E 102°10'34.7"), revealed a concerning subsurface profile characterized by persistently low resistivity values throughout the depth range of 8.27 to >158 meters. The progressive decrease in resistivity from 17.96 Ωm at shallow depths to 3.47 Ωm at depths exceeding 158 meters indicates continuously saturated, unconsolidated clayey sediments lacking competent aquifer characteristics (Table 6).

Table 6. Geoelectric Characteristics at Track 4 (Student Center)

Layer	Depth Interval (m)	Resistivity (Ωm)	Lithological Interpretation
1	0.00–4.68	579.21	Surficial coarse sediments
2	4.68–8.27	569.01	Sand, gravel, and pebbles
3	8.27–29.81	17.96	Moist clayey sand
4	29.81–40.20	10.64	Saturated soft clay and sand
5	40.20–106.74	6.32	Continuously saturated sediments
6	106.74–158.48	4.80	Water-saturated soft formations
7	>158.48	3.47	Deep saturated clay-dominated layers

From a hydrogeological engineering perspective, this location presents significant challenges for groundwater extraction. The absence of well-defined aquifer layers with adequate structural integrity, combined with extreme depth requirements (>160 meters) for potentially productive zones, renders

drilling operations economically impractical and technically challenging. The installation of well screens in such deep, unconsolidated formations would be problematic due to structural instability and high operational costs.

Water quality analysis from the Student Center location (Table 7) revealed a critical non-compliance issue: the measured pH of 8.64 exceeds the maximum regulatory threshold of 8.5 established for potable water. This alkaline pH indicates potential corrosive properties that could affect distribution infrastructure and gastrointestinal tolerance, rendering the water unsuitable for direct consumption. However, parameters including temperature (25°C), TDS (376 mg/L), turbidity (0.64 NTU), color (0.460 PtCo), and odor (absent) remained within acceptable ranges, suggesting the water could be utilized for non-potable applications following pH adjustment treatment.

Table 7. Water Quality Assessment at Student Center Location

Parameter	Measured Value	Regulatory Standard	Compliance Status
Temperature	25°C	20–25°C	Compliant
TDS	376 mg/L	<500 mg/L	Compliant
Turbidity	0.64 NTU	<5 NTU	Compliant
Color	0.460 PtCo	<15 PtCo	Compliant
Odor	Odorless	Odorless	Compliant
pH	8.64	6.5–8.5	Non-compliant

Integrated Hydrogeological Interpretation and Water Quality Discussion

The comprehensive geoelectric survey across four distinct tracks within the UIN Fatmawati Sukarno Bengkulu campus reveals significant spatial heterogeneity in subsurface hydrogeological conditions. This variability reflects the complex depositional environment characteristic of the Selebar Subdistrict, where alluvial, fluvial, and potentially marine-influenced sedimentary sequences have created diverse aquifer systems.

Temperature measurements across all sampling locations uniformly recorded 25°C, representing optimal conditions for potable water applications. This thermal stability reflects equilibrium with ambient subsurface geothermal gradients and indicates minimal influence from anthropogenic thermal pollution sources. Water temperatures within the 20-25°C range optimize chemical stability, minimize microbial proliferation rates, and ensure palatability for human consumption (WHO, 2017).

Total Dissolved Solids (TDS) values demonstrated considerable spatial variation, ranging from 154 mg/L (Track 1) to 376 mg/L (Student Center). All measured

values remained substantially below the WHO maximum threshold of 500 mg/L, indicating acceptable mineral content for drinking water. The elevated TDS at the Student Center location (376 mg/L), while compliant with regulatory standards, approaches the upper limit and suggests increased ionic concentration potentially attributable to extended groundwater residence time, enhanced water-rock interaction, or anthropogenic contamination influences. Waters with TDS below 300 mg/L (Tracks 1-3) represent optimal quality for direct consumption without palatability concerns.

Turbidity analysis revealed generally excellent water clarity, with three locations exhibiting values below 1 NTU, consistent with WHO recommendations for ideal drinking water. The Track 3 (Library) location recorded elevated turbidity (2.11 NTU), indicating suspended particulate matter potentially originating from colloidal clay particles, organic materials, or microbial content. While remaining within the acceptable limit of 5 NTU, this elevated turbidity suggests the potential benefit of pre-treatment filtration to achieve optimal aesthetic and microbiological water quality.

Color assessment across all locations demonstrated exceptional performance, with values ranging from 0.181 to 0.460 PtCo, substantially below the regulatory maximum of 15 PtCo. These low color values indicate minimal dissolved organic matter, absence of metallic ion contamination (particularly iron and manganese), and effective natural filtration through subsurface sedimentary matrices.

The pH analysis revealed a critical differentiation among sampling locations. Three locations (Tracks 1-3) exhibited pH values within the optimal neutral range (7.95-8.35), indicating balanced water chemistry suitable for direct consumption. However, the Student Center location demonstrated elevated alkalinity (pH 8.64), exceeding the regulatory maximum of 8.5. This alkaline deviation may result from prolonged interaction with carbonate-bearing geological formations, potentially enhanced by the deep circulation pathways suggested by geoelectric interpretation. Elevated pH can induce bitter taste characteristics, promote scale formation in distribution systems, and potentially affect gastrointestinal tolerance, particularly for individuals with sensitive digestive systems.

The integrated interpretation of geoelectric data and water quality parameters enables strategic recommendations for groundwater resource development. Tracks 1 and 2 represent priority locations for groundwater extraction, offering both accessible aquifer depths (10-70 meters) and excellent water quality characteristics suitable for direct potable

use. Track 3 (Library) provides a substantial confined aquifer resource requiring minimal pre-treatment (turbidity reduction) for potable applications. Conversely, the Student Center location is not recommended for groundwater development due to unfavorable hydrogeological conditions (excessive depth, unconsolidated formations) and water quality concerns (elevated pH), despite acceptable performance in other parameters.

These findings contribute significantly to sustainable campus development planning by providing evidence-based hydrogeological data essential for water resource management decision-making. The research demonstrates the efficacy of integrated geophysical and hydrochemical assessment methodologies in characterizing groundwater resources within rapidly developing urban-academic environments, establishing a replicable framework applicable to similar institutional contexts globally

Conclusions

This comprehensive hydrogeological investigation successfully characterized groundwater resources within the UIN Fatmawati Sukarno Bengkulu campus through integrated application of geoelectric resistivity surveying and systematic water quality assessment. The research identified spatially heterogeneous aquifer systems, delineating two principal groundwater-bearing formations: shallow unconfined aquifers positioned at 9.94-25.53 meters depth with approximately 15.59 meters thickness, and deeper confined aquifers extending beyond 161.43 meters depth. Resistivity values ranging from 0.93 to 6.74 Ωm confirmed water-saturated clayey sandstone lithologies characteristic of productive aquifer formations in alluvial-fluvial depositional environments.

Water quality analysis demonstrated that groundwater from Tracks 1, 2, and 3 locations achieved full compliance with potable water standards established in Minister of Health Regulation 32/2017, exhibiting acceptable parameters across temperature, pH, turbidity, TDS, color, and odor assessments. However, the Student Center location revealed compromised water quality (pH 8.64 exceeding regulatory threshold of 8.5) coupled with unfavorable hydrogeological conditions (excessive drilling depth requirements >160 meters, unconsolidated formations), precluding recommendation for groundwater development at this site.

The practical implications of these findings enable evidence-based spatial planning for campus water resource infrastructure, prioritizing Tracks 1 and 2 for immediate groundwater development while

recognizing Track 3 as requiring minimal pre-treatment intervention. These results establish a critical baseline dataset supporting sustainable groundwater management protocols aligned with institutional expansion requirements while preserving hydrological ecosystem integrity.

Limitations of this investigation include the one-dimensional nature of geoelectric sounding interpretation, which assumes horizontal layer stratification and may not fully resolve complex three-dimensional geological structures. Future research should incorporate resistivity tomography techniques for enhanced spatial resolution, implement long-term groundwater level monitoring to assess aquifer recharge dynamics, conduct comprehensive hydrochemical analysis including trace element and isotopic characterization, and develop numerical groundwater flow models to optimize extraction rates while preventing aquifer depletion.

The methodological framework established through this research provides a replicable template for hydrogeological assessment in comparable urban-academic contexts, contributing to the broader scientific understanding of groundwater resource characterization in rapidly developing tropical regions

Author Contributions

Fadilah: Conceptualization, Methodology, Field Investigation, Data Analysis, Writing—Original Draft Preparation, Visualization. Marulak Simarmata: Supervision, Validation, Writing—Review and Editing. Muchammad Farid: Methodology, Formal Analysis, Software. Sukisno: Resources, Validation, Writing—Review and Editing. All authors have read and approved the final manuscript.

Funding

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this manuscript.

Acknowledgments

The authors express gratitude to Universitas Bengkulu for technical and analytical support, and to UIN Fatmawati Sukarno Bengkulu for facilitating field access and providing institutional resources essential for completing this investigation.

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