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Groundwater Identification Using the Geoelectric Method (Electrical Resistivity Tomography/ERT) For the Utilization of Mining Areas

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ABSTRACT. Research conducted in Pomalaa Subdistrict, Kolaka Regency, Southeast Sulawesi, aimed to identify the potential and characteristics of groundwater in an area with complex geological conditions, dominated by ultramafic and sedimentary rocks. To achieve this objective, a multidisciplinary approach was used, including geological and hydrogeological mapping and field geoelectric testing. One of the main methods used in this study was Electrical Resistivity Tomography (ERT), which produces two-dimensional subsurface images from variations in the electrical resistivity of soil and rock. The analysis results show that ultramafic rocks in this region have the potential to serve as free aquifers with moderate to high hydraulic conductivity, making them a source of clean water for the local community's domestic needs. Meanwhile, the southwestern zone, composed of sedimentary rocks, hosts a confined aquifer with high permeability and a relatively low water table, making it a more accessible groundwater source. The integration of all geological, hydrogeological, and geophysical data provides a comprehensive picture of groundwater distribution and quality in the Pomalaa region. These findings provide a strong scientific basis for supporting strategies for the conservation and sustainable use of groundwater resources, as well as for making.

Keywords: Confined and unconfined aquifer · Electrical resistivity tomography · Pomalaa · Ultramafic and sedimentary rocks.

1 INTRODUCTION

Pomalaa, Kolaka Regency, Southeast Sulawesi, is located on the west coast of southeastern Sulawesi Island, covering an area of approximately 231.47 km² divided into 12 villages (Figure 1). This subdistrict has experienced rapid demographic and economic growth, with an average population increase of 1.12% per year and a total population of 38,472 (Badan Pusat Statistik Kabupaten Kolaka, 2024). The mining industry has also grown significantly, especially in coastal areas. (Irawati, 2023). The combined effects of population growth and urbanization have led to excessive exploitation of groundwater, especially in coastal areas, which has the potential to cause a decline in the water table and seawater intrusion (Pattison & Cooke, 2024).

Several studies have investigated the potential of groundwater in Pomalaa using various approaches, including geophysical sur-

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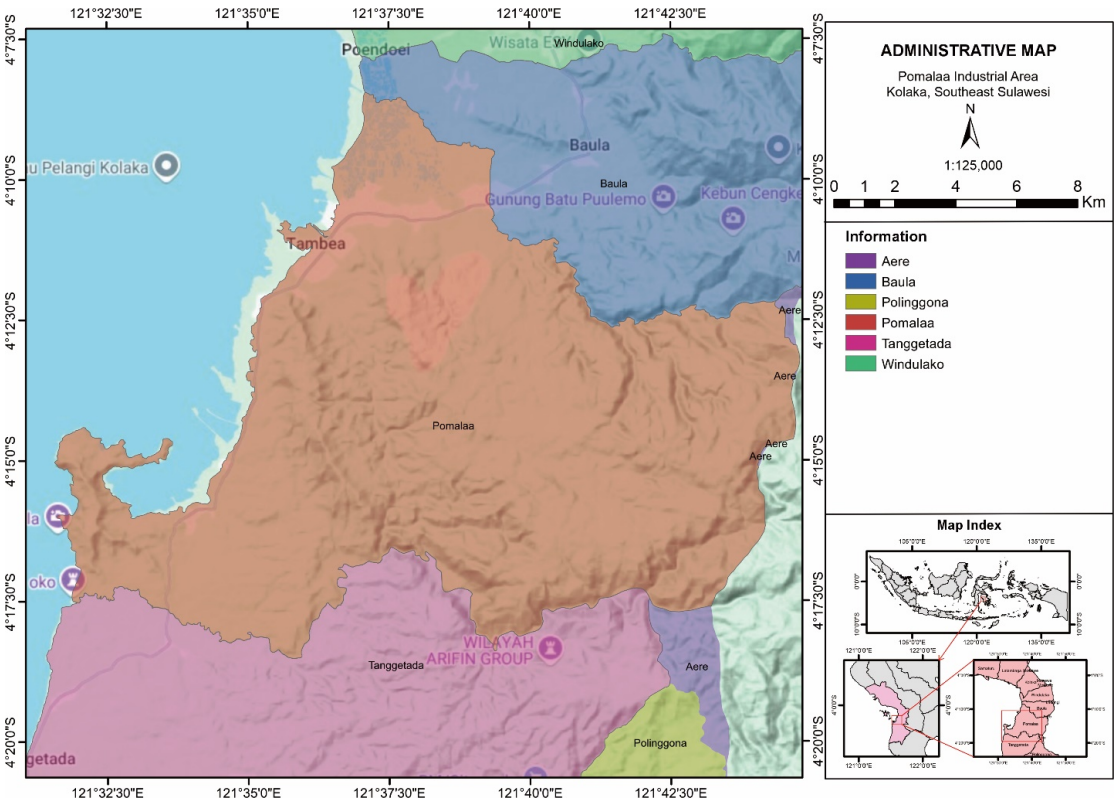

FIGURE 1. Research location map including 6 subdistricts in Kolaka Regency (Google, 2025) and DEMNAS (Badan Informasi Geospasial, 2021).

veys (Ruslan et al., 2025; Ghiffari et al., 2025; Pahlawantika et al., 2025), geological mapping (Sugiono et al., 2024) and hydrogeology (Steven et al., 2021). However, most of this research focuses primarily on analyzing the resistivity of groundwater potential in ultramafic rocks and sediments using field data. Resistivity data is used to correlate results from geological mapping and subsurface drilling. This provides comprehensive results for identifying groundwater in these two rock types. Therefore, an integrated approach that combines geological characterization, field-based data, and resistivity validation is needed to improve the reliability of groundwater potential assessments in coastal areas.

Geologically, the presence of groundwater in Pomalaa is likely related to sediment remnants trapped in sediment layers and through fractures/cracks in ultramafic rocks (Davis & De Wiest, 1966). From a hydrogeological perspective, anomalies in groundwater flow patterns may reflect ancient seawater traps within shallow aquifers (Domenico & Schwartz, 1998). Previous studies have shown that groundwater potential significantly reduces groundwater availability (Rahmawati et al., 2024), with vulnerability influenced by variations in lithology, geomorphological conditions, geological structure, and hydrology (Surono, 2013), and anthropogenic activities such as mining, which can disrupt the movement of seawater onto land (Ramadhan et al., 2020). This problem is particularly serious because continued groundwater extraction will lead to a decline in groundwater levels and soil/rock strength (Fessahaye et al., 2025).

The massive exploitation of groundwater in nickel mining areas, particularly in tropical coastal regions such as Pomalaa, Southeast Sulawesi, has involved both shallow (confined) and deep (unconfined) aquifers. Intensive industrial activity, coupled with population growth and land use changes, has increased pressure on the groundwater system as a whole. The extraction of water from confined aquifers for domestic and industrial processes, as well as the exploration of unconfined aquifers for sustainable supply, has caused significant changes in regional hydraulic gradi-

ents. Study by (Fessahaye, 2025) shows that uncontrolled groundwater exploitation in mining zones can accelerate the migration of the saltwater interface toward land, especially when the recharge zone is disturbed by mining activities and heavy infrastructure development. When brackish wells begin to appear in areas previously classified as active recharge zones, this indicates a disruption in the natural hydraulic balance and the need for zoning-based conservation strategies and continuous monitoring (Custodio, 1987; Ferguson & Gleeson, 2012). Understanding the interaction between anthropogenic pressures and aquifer dynamics is essential for designing adaptive and sustainable groundwater management policies in tropical mining areas.

To address these challenges, this study applied several methods, namely electrical resistivity tomography (ERT), geological mapping, and geological drilling. Analysis of these three methods can be used to identify and characterize groundwater potential. The main objective is to improve the understanding of groundwater potential and provide a scientific basis for sustainable groundwater management in the Pomalaa coastal area.

2 GEOLOGICAL SETTING/SITE CHARACTERIZATION

The geological setting of the study area consists of seven main lithological units arranged from oldest to youngest: Mekongga Complex, Ultramafic Complex, Pompangeo Complex, Langkowala Formation, Boepinang Formation, Alangga Formation, and Alluvial Deposits (Figure 2) (Simandjuntak et al., 1993). These formations collectively reflect the geological evolution of the Pomalaa coastal zone, which has been shaped by shallow marine sedimentation, tectonic uplift, and subsequent anthropogenic modification along the coastline.

3 METHODOLOGY

This study uses a combination of field data collection, studio analysis, and 3-dimensional modelling using the Electrical Resistivity Tomography method to assess groundwater potential in ultramafic rocks (unconfined aquifers) and sedimentary rocks (confined aquifers). The materials used include both primary and secondary datasets. Primary data were obtained through field observations and drilling at 13 exploration wells spread across the Pomalaa District. Drilling locations were determined based on geological mapping and geophysical testing to obtain a general overview of the surface and subsurface geophysics. At each drilling location, lithological descriptions and several geophysical logging tests were conducted. Geological mapping was carried out in July 2025, electrical resistivity tomography (ERT) tests were conducted from 2023 to 2024, drilling was carried out from 2020 to 2024, and geophysical logging was conducted from 2020 to 2024. Secondary data included topographic, geological, and hydrogeological maps, as well as administrative boundaries (Table 1). This study used a combination of field data collection, studio analysis, and 3D modelling using the ERT method to determine groundwater potential in ultramafic rocks (unconfined aquifers) and sedimentary rocks (confined aquifers).

The main analytical framework used in this study was designed to obtain a comprehensive characterization of aquifers in the study area using an integrative approach involving geophysical surveys using the Electrical Resistivity Tomography (ERT) method, surface geological mapping, exploratory drilling, and geophysical logging. The ERT survey was conducted to identify the lateral and vertical distribution of subsurface resistivity, which represents variations in lithology and groundwater saturation zones. This method was chosen for its ability to produce two-dimensional images of shallow to intermediate geological structures, as well as its sensitivity to changes in rock moisture and porosity, as explained by Balasco et al. (2022): "ERT is a robust and well-consolidated method largely applied in near-surface geophysics". Geological mapping is carried out systematically to identify rock units, geological structures, and potential infiltration zones, which then form the basis for determining drilling points. Geological drilling is carried out at locations where resistivity anomalies and lithological transition zones are identified, with the aim of obtaining actual stratigraphic data and rock samples for laboratory analysis. Furthermore, geophysical logging is performed in boreholes to measure physical parameters such

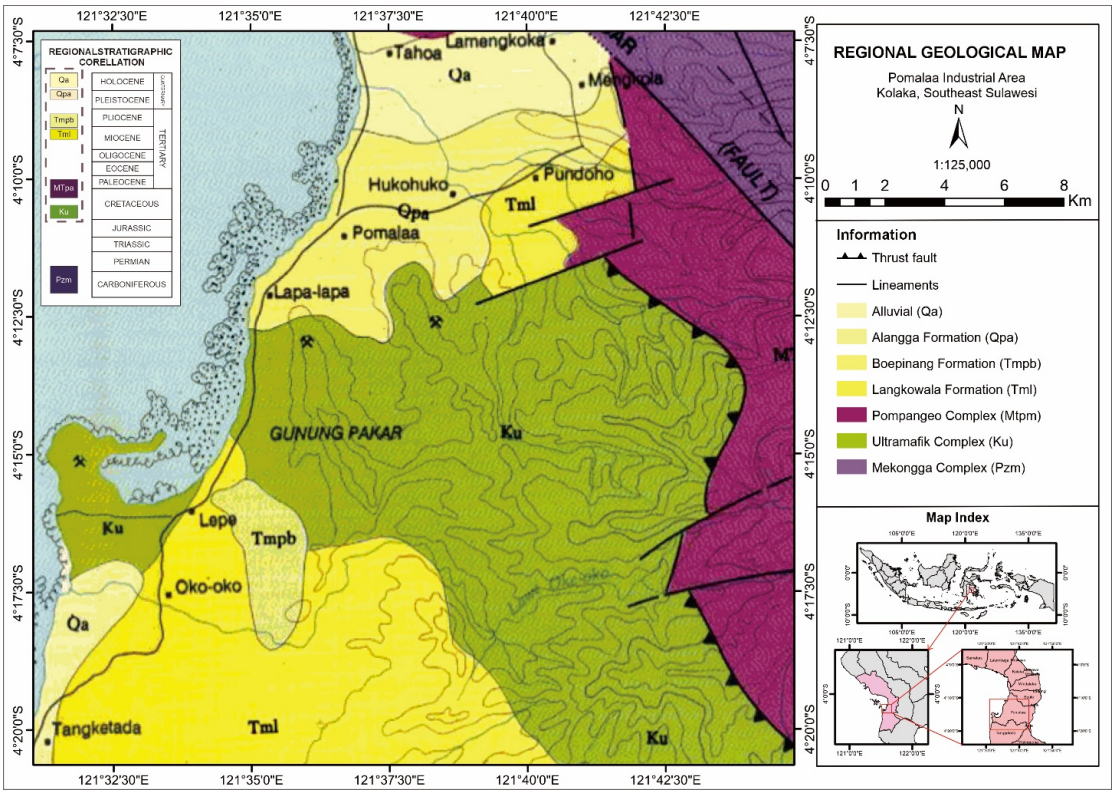

FIGURE 2. Regional geological map of the study area (Simandjuntak & Surono, 1993).

TABLE 1. Groundwater identification research data.

Data type	Data source	Data category	Description
Primary	Electrical Resistivity Tomography (ERT) Test	Geophysics	Field Measurements
	Geological Mapping	Geology	Field Measurements
	Geological Drilling		
	Geophysical Logging	Geophysics	
Secondary	Regional Geological Map	Geology	Literature Study (Simandjuntak, T., Surono, 1993)
	Regional Hydrogeological Map	Hydrogeology	Literature Study (Direktorat Geologi Tata Lingkungan, 1984; Arifin, 2008)

as resistivity, conductivity, and natural gamma, which are useful for validating ERT results and correlating aquifer layers (Figure 3). The integration of these four methods enables a more accurate interpretation of the aquifer system, in terms of geometry, continuity, and groundwater potential, and supports the development of an applicable hydrogeological model for the conservation and management of groundwater resources in tropical mining areas.

The configuration for ERT geophysical measurements uses the Wenner-Alpha configuration. The Wenner-Alpha electrode arrangement positions the current electrodes A and B and the potential electrodes M and N symmetrically on either side of the centre point. The distance between the four electrodes is equal to α, with potentials P1 and P2 located halfway between C1 and C2 (Telford et al., 1990). The target depth achievable with the ERT method using the Wenner-Alpha configuration is $a/2$, the spacing between electrodes at which the distance between the current and potential electrodes is equal (Figure 4). Thus, the expected results can be adjusted through the spacing between electrodes. The Wenner-Alpha configuration is very sensitive to local lateral and shallow changes. This is because anomalies below the surface are observed by the C and P electrodes multiple times (Loke, 2000).

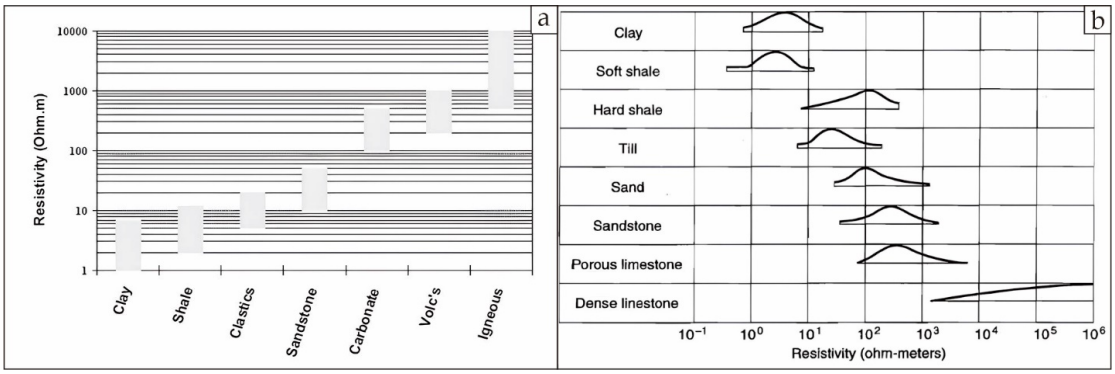

FIGURE 3. (a) Resistivity Values of Several Types of Rocks (Telford *et al.*, 1976); (b) Resistivity Values of Several Types of Sediment under Freshwater Saturation Conditions (Todd & Mays, 2005).

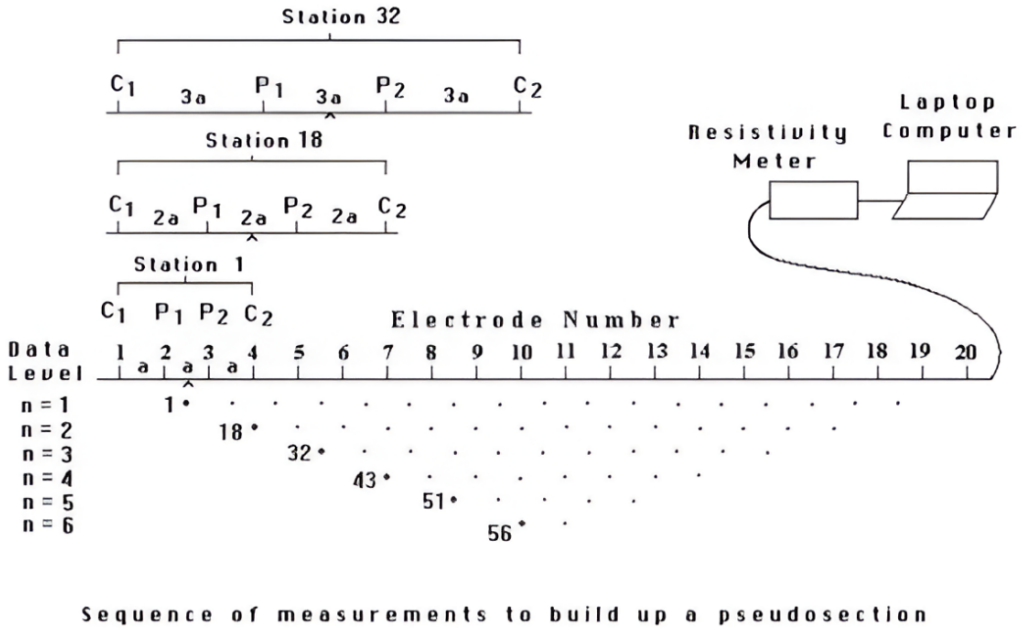

FIGURE 4. Electrode arrangement in 2D geophysical measurements using the Wenner Alpha configuration and the measurement sequence used to construct the pseudosection (Loke, 2000).

4 RESULTS AND DISCUSSION

Geological mapping was conducted to cover various aspects, including lithological characteristics, geological structures, and hydrogeological conditions in the study area. From the mapping results, 26 observation locations were identified as research points to obtain more comprehensive data on local geological conditions (Figure 5). The following is the data obtained from the mapping results (Table 2).

Hydrogeological and subsurface geological exploration activities in the Pomalaa Industrial Area, Kolaka Regency, Southeast Sulawesi, have produced integrated mapping covering 13 exploration wells and 5 resistivity zones based on the Electrical Resistivity Tomography (ERT) method (Figure 6). The successfully drilled well points include A, B, E, I, MW, A-1, B-1, B-2, D-1, E-1B, MW-1, M2-2, and MW-3, which are spatially distributed throughout the study area and represent variations in lithology and local hydrogeological conditions. Each well point was used as a vertical reference for geophysical data validation and subsurface stratigraphic correlation.

ERT mapping produced five main resistivity zones, namely Zones 1, 2, 3, and 4 in sedimentary formations consisting of sandstone and conglomerate of the Langkowala Formation. Meanwhile, the 2023 zones in the ultramafic formation, consisting of peridotite from the Ultramafic Complex Formation, exhibit distinct re-

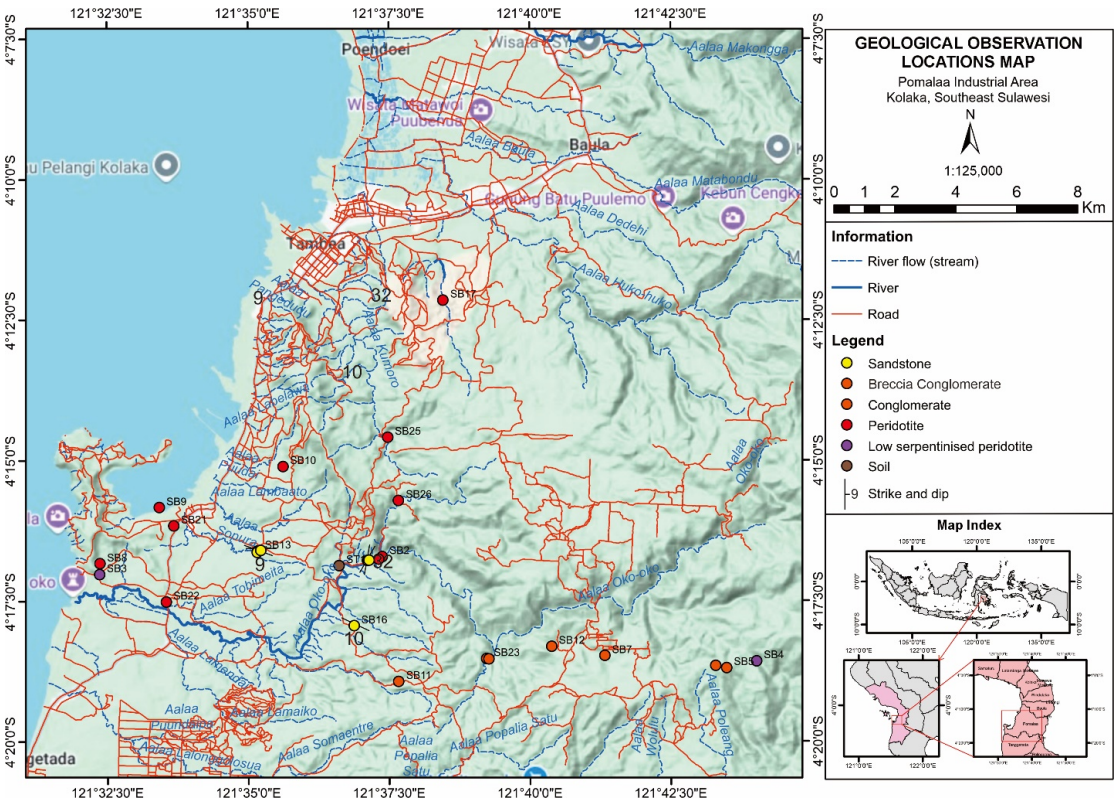

FIGURE 5. Geological mapping location map.

TABLE 2. Geological mapping data.

STA code	Coordinates X	Coordinates Y	Colour	Degree of weathering	Structure	Particle shape	Spacing (cm)	Lithology
ST1	345775	9526646	Red	Residual soil	Non structure (fine)	Clay	None	Soil
SB2	347186	9526941	Grey	Slightly weathered	Massive	Angular, flat, smooth	0.1–0.25 mm	Peridotite
SB3	337910	9526343	Greenish grey	Slightly to moderately weathered	Massive	Angular, flat, rough	0.1–0.25 mm	Low serpentinised peridotite
SB4	359484	9523518	Greenish grey	Highly weathered	Massive	Angular, flat, rough	0.1–0.25 mm	Low serpentinised peridotite
SB5	358498	9523287	Brownish grey	Moderately weathered	Massive	Sub-rounded to rounded	None	Conglomerate breccia

sistivity characteristics that correlate with rock type and groundwater saturation levels. These zones are interpreted as representing lithological variations, ranging from alluvial layers and sedimentary rocks to ultramafic rocks that dominate the southern part of the study area. The integration of well data and ERT zones enables more accurate identification of aquifer presence, saturated layer thickness, and potential infiltration and discharge zones.

The results of regional hydrogeological interpretation in the Pomalaa Industrial Area, Kolaka Regency, Southeast Sulawesi, indicate the existence of two main groundwater basin systems that are spatially and hydraulically separated, namely the Kolaka Groundwater Basin and the Tangketada Groundwater Basin (Figure 7). These two basins exhibit different recharge characteristics in unconfined and confined aquifers, as identified through topographic analysis, river flow direction, and elevation distribution.

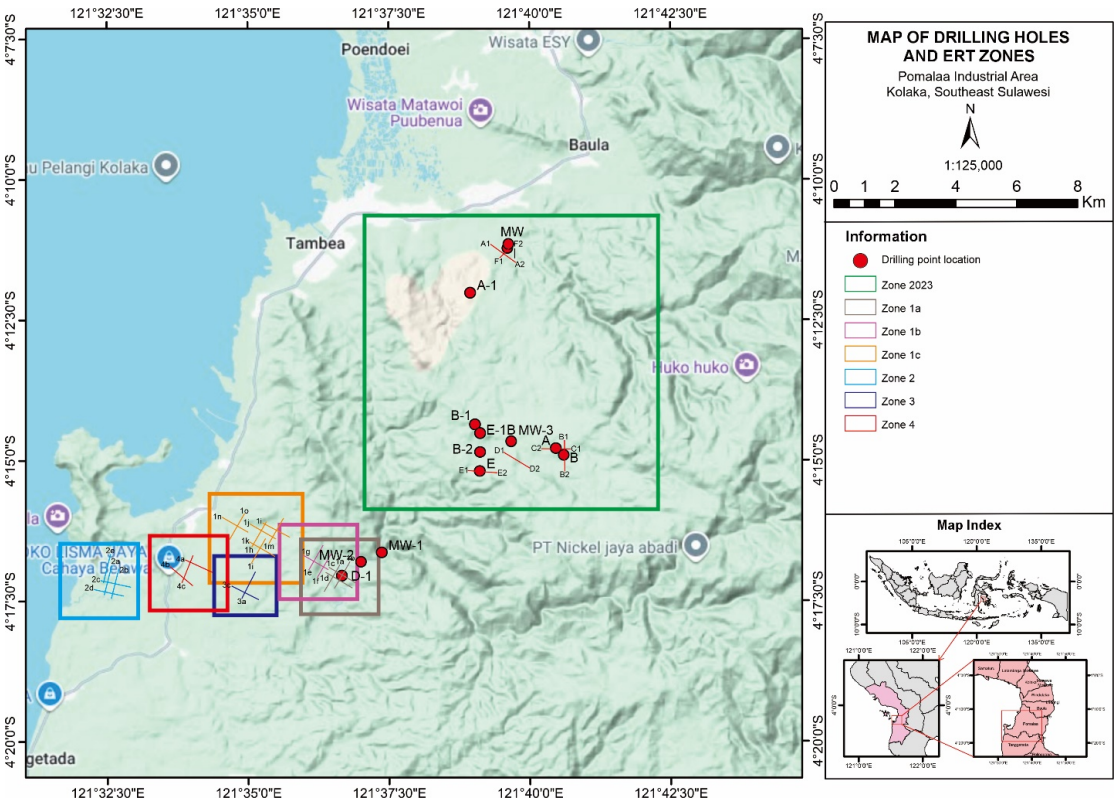

FIGURE 6. Drilling location map and ERT cross-section zone.

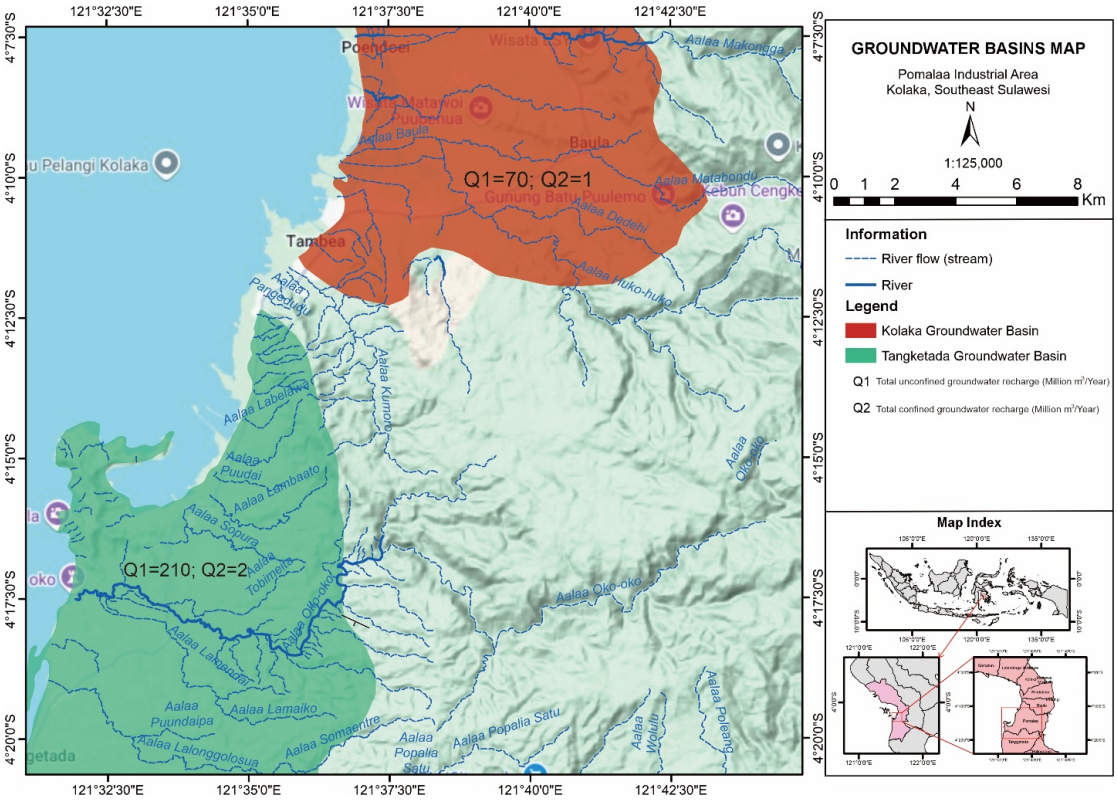

FIGURE 7. Groundwater potential and basin map.

In the northern region, the Kolaka Basin shows recharge values of Q_1 = 70 m^3/year for unconfined aquifers and Q_2 = 1 million m^3/year for confined aquifers. These values

reflect the dominance of limited surface infiltration processes, with the main contribution coming from river flow and local runoff. In contrast, in the southern part, the Tangketada Basin has higher recharge values, namely Q_1 = 210 m^3/year for unconfined aquifers and Q_2 = 2 m^3/year for confined aquifers, indicating a more extensive and intensive recharge zone, supported by more complex slope morphology and river networks.

This recharge distribution shows that unconfined aquifers are more responsive to surface conditions and rainfall, while confined aquifers tend to receive recharge from deeper and more localized recharge zones. The difference in Q_1 and Q_2 values between the two basins provides important indications for groundwater conservation planning, infiltration zone management, and mitigation of the risk of overexploitation in tropical mining areas.

The results of geological and regional geological mapping show that the study area consists of five rock units, namely the Pompango Complex Metamorphic Rock Unit (Limestone), the Pomalaa Peridotite Unit (Limestone) composed of peridotite, basalt, and serpentinite, the Langkowala Conglomerate Unit (Miocene) composed of conglomerate breccia and conglomerate, the Langkowala Sandstone Unit (Miocene) composed of sandstone, mudstone, claystone, and siltstone, and Alluvial Deposits (Holocene) composed of clay, silt, and sand (Figure 8). The regional structure is relatively oriented northeast-northwest, indicating that the study area is still active/has the potential for continued tectonic development. Faults are weak zones that allow water to escape, so groundwater potential is high when extracted near the structural zone.

The subsurface geological model of the Pomalaa Industrial Area shows two dominant zones: the northern zone consists of massive, non-aquiferous ultramafic rocks, while the southwest zone consists of sedimentary rocks with potential to be productive aquifers. The three main stratigraphic units—Pomalaa Peridotite, Langkowala Sedimentary Rocks, and Alluvial Deposits—form a complex regional geological framework. Joint structures in ultramafic rocks and intergranular porosity in sedimentary rocks are the main controllers of groundwater distribution, which supports the development of conceptual aquifer models and sustainable exploration strategies.

The interpretation of Electrical Resistivity Tomography (ERT) cross-sections in the ultramafic rock zone of the Pomalaa Industrial Area shows the presence of a subsurface layer with low resistivity (<30 Ω·m), which indicates hydrogeological conditions of water saturation (Figure 9). Although ultramafic rocks such as peridotite generally have high resistivity due to their massive texture and ultrabasic mineralogy (olivine, pyroxene), groundwater in this zone is controlled by intensively developed fractures (Figure 10). Massive fractures with dense to moderate spacing function as secondary permeable pathways that allow groundwater infiltration and movement through rock joints. This resistivity distribution reinforces the interpretation that the aquifer system in ultramafic rocks is fracture-controlled, with storage capacity and transmissivity depending on the degree of fracture connectivity. These findings confirm that although ultramafic rocks are not primary aquifer rocks, their internal geological structure can create hydrogeological conditions that support groundwater occurrence, especially in weathering zones and active fractures. Therefore, understanding the fracture pattern and resistivity distribution is key to planning groundwater resource exploration and conservation in complex geological environments such as Pomalaa.

The interpretation of Electrical Resistivity Tomography (ERT) cross-sections in the sedimentary rock zone in the Pomalaa Industrial Area shows the presence of a subsurface layer with low to moderate resistivity values, ranging from 10–50 Ω·m, which hydrogeologically indicates water saturation conditions. This zone is spatially associated with sandstone, claystone, and conglomerate units that are arranged in horizontal layers, as shown in the geological profile and ERT inversion results (Figure 11). The occurrence of groundwater in sedimentary rocks is controlled by intergranular porosity, where pore spaces between mineral grains allow for effective infiltration and movement of water. The lithology of sandstone and conglomerate shows high effective porosity, with moderate to high permeability, thus function-

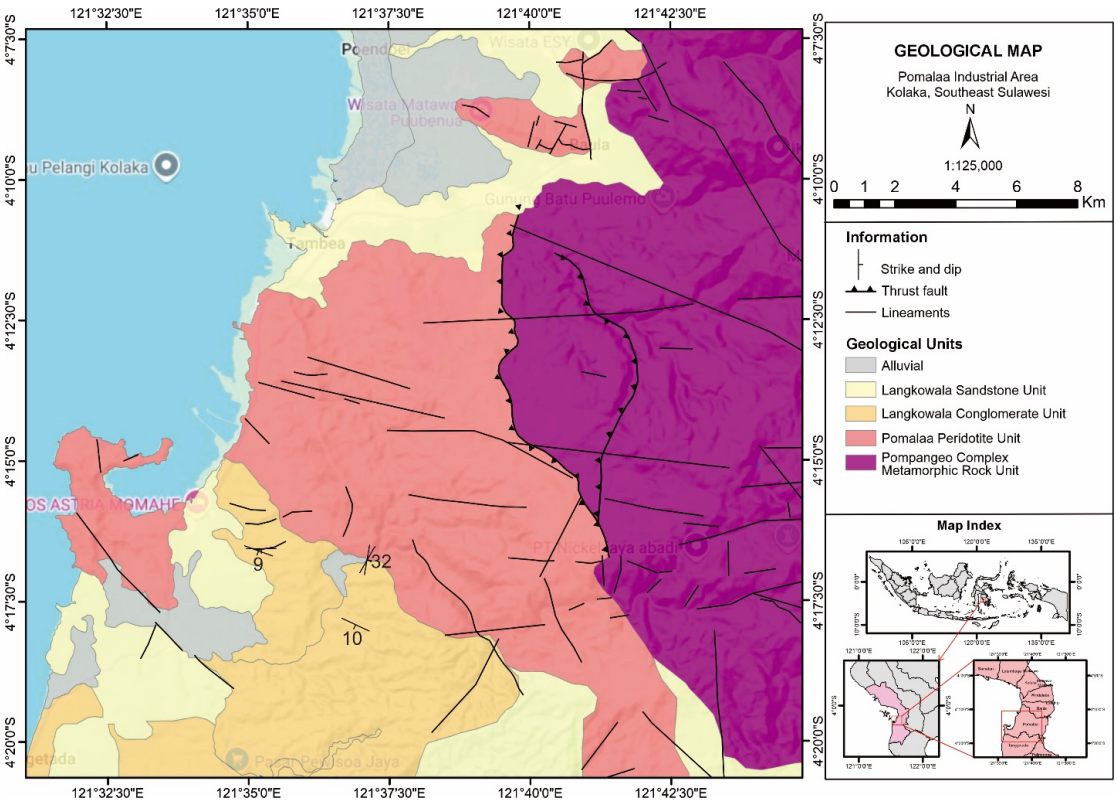

FIGURE 8. Geological map.

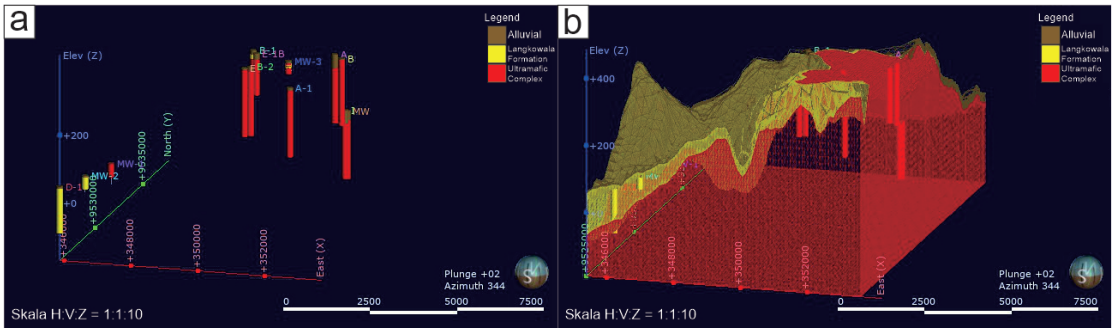

FIGURE 9. (a) Profile of geological drilling data distribution results; (b) Subsurface geological model.

ing as a productive aquifer. Conversely, impermeable claystone acts as a confining layer, directing groundwater flow laterally. The distribution of low resistivity in the sandstone and conglomerate zones supports the interpretation that groundwater continuously fills the pore space. These findings confirm that sedimentary rocks in the study area have significant potential as primary aquifers and that intergranular porosity characteristics are a dominant factor in determining groundwater storage capacity and transmissivity. Therefore, understanding lithological distribution and resistivity values is essential in planning exploration and conservation of groundwater resources in tropical sedimentary geological environments.

5 CONCLUSION

Based on the results of geological, hydrogeological, and geophysical investigations in the Pomalaa Industrial Area, it can be concluded that the stratigraphic configuration and local geological structure play an important role in controlling the aquifer system and groundwater distribution. The presence of productive aquifers in sedimentary and alluvial units, as well as fracture systems in ultramafic rocks, indicates that groundwater potential in this region is strongly influenced by the litholog-

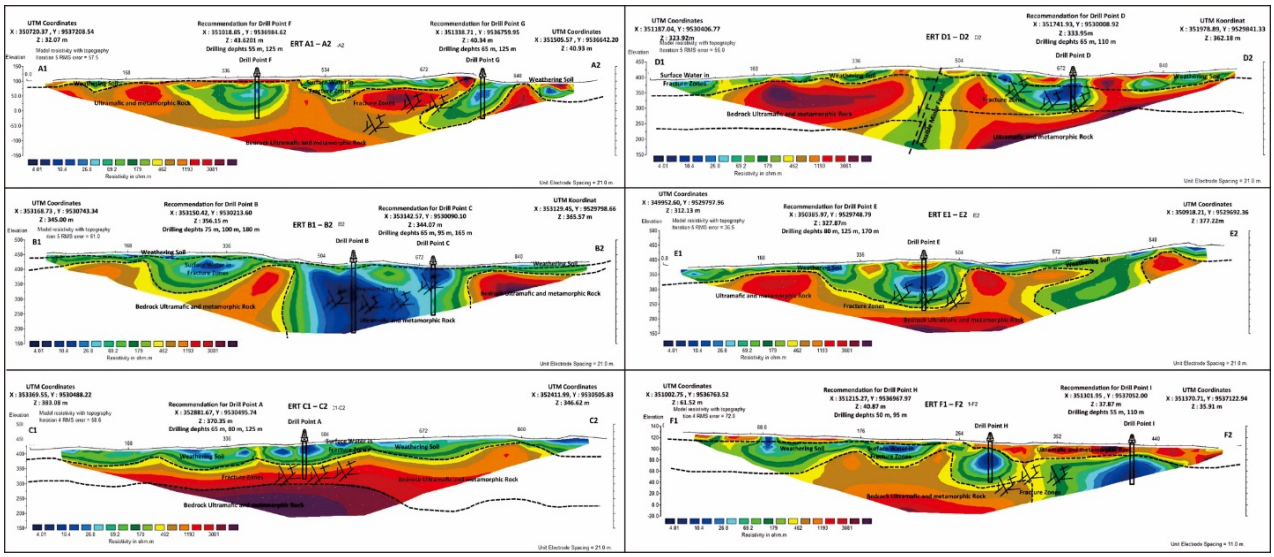

FIGURE 10. ERT profile and cross-section of the ultramafic rock zone.

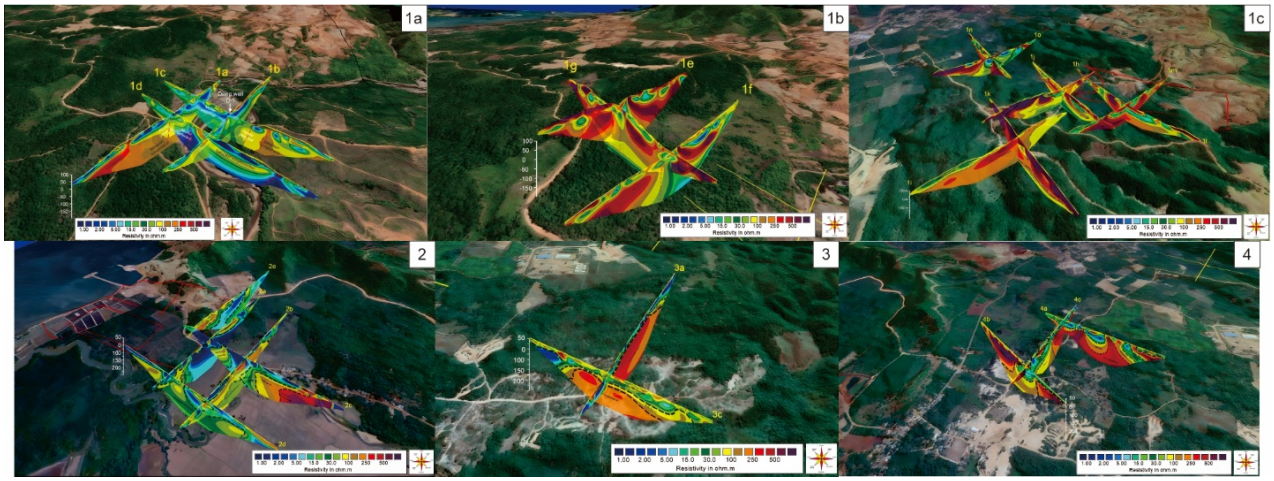

FIGURE 11. ERT profile and cross-section of the sedimentary rock zone.

ical characteristics and internal structures of the rocks. The integration of exploration well data and subsurface resistivity mapping enables more accurate delineation of recharge and discharge zones and the identification of two hydraulically distinct groundwater basin systems. These findings provide a strong scientific basis for developing groundwater conservation strategies and sustainable exploration planning in tropical mining areas. Further research is recommended to test aquifer dynamics over time and evaluate the recovery capacity of groundwater resources under industrial exploitation pressure.

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