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RESEARCH ARTICLE

Subsurface Alteration Characteristics Due to Hydrothermal Influence Using the Geoelectrical Method in the Ie Seu'um Geothermal Area, Aceh Besar, Indonesia

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Abstract

Research on subsurface alteration due to hydrothermal fluid influence was conducted in the hydrothermal manifestation area of Mesjid Raya District, Aceh Besar, Aceh. Data was acquired using the electrical resistivity method with a Wenner–Schlumberger configuration along four survey lines. Survey Lines 1 and 2, each 106.5 m long with 1.5 m electrode spacing, represent Zone 1, which is located directly at the hot spring source. Survey Lines 3 and 4, each 210 m long with 3 m electrode spacing, represent Zone 2, located 3.5 km from Zone 1 and 2 unaffected by hot fluid flow. This study aimed to identify the geothermal influence on subsurface characteristics. The results revealed clear differences in the resistivity profiles between Zones 1 and 2, with resistivity variations ranging from 0–600 Ωm and 0–5000 Ω·m, respectively. Interpretation indicates that Zone 1 consists of hydrothermally altered volcanic rocks, while Zone 2 comprises alluvium affected by weathering in the unsaturated (vadose) zone under meteoric water influence. These subsurface alterations provide essential evidence of geothermal impacts on rock characteristics. The findings also support the interpretation that the Ie Seu'um geothermal system is strongly concentrated in Zone 1, whereas surrounding areas show weaker manifestations that do not support the development of an active geothermal system.

Keywords: Resistivity, Geothermal, Ie Seu'um, Geoelectrical, Subsurface Alteration

1. Introduction

Indonesia is estimated to possess geothermal energy potential of approximately 28,617 MWe, or about 40% of the world's total geothermal resources. In addition to its energy potential, volcanic areas in Indonesia have also been developed into geotourism sites, providing direct economic benefits to local communities. The abundant geothermal potential is distributed across 331 prospects from Sabang to Marauke (Direktorat Panas Bumi, 2017). However, only a small portion of this potential has been developed into geothermal power plants or geotourism sites (Trisnaning, 2025). In Aceh Province alone, there are 20 geothermal prospects, including Jaboi, Peut Sagoe, and Seulawah Agam volcanoes, with an estimated combined potential of around 165 MWe (Hochstein et al., 2008; Idroes et al., 2019; Marwan et al., 2020; Yanis et al., 2020; Marwan et al., 2021; Zaini et al., 2021; Yanis et al., 2022; Abdullah et al., 2022).

Geothermal energy is a natural heat resource stored within the Earth's crust. Surface manifestations are thought to occur due to heat conduction from deeper zones or through fractures that allow hot fluids to migrate to the surface (Saputra et al., 2020). The existence of a geothermal system in an area will not exist if the components of the geothermal system are not met (Taufan et al., 2020). According to Saburu et al., (2022), geothermal manifestations at the surface include hot springs, mud pools, geysers, warm ground, steaming ground, hot ponds, fumaroles, silica sinter deposits, and hydrothermally altered rocks.

The formation of geothermal systems is strongly influenced by geological processes along volcanic belts, including magmatic activity and magma emplacement during volcanic eruptions (Riputra et al., 2021). Nearly half of Indonesia's geothermal potential is located on the island of Sumatera. One of the regions in Sumatera with geothermal energy potential is Aceh Province (Idroes et al., 2018). Aceh Province is located on the western Sumatera island with consist of four active major volcanoes mountains namely as Burni Telong mountain, Peuet Sagoe mountain, Jaboi Mountain, and Seulawah Agam mountain which are more active compare from others. Generally, high temperature of 150-225°C dominated for this geothermal environment in Indonesia region (Taqiuddin et al., 2016).

Aceh Province hosts several geothermal prospects, including the Ie Seu'um geothermal field in Aceh Besar (Hidayat et al., 2018). The Ie Seu'um hot spring is in Ie Seu'um Village, Mesjid Raya District, Aceh Besar Regency. Geographically, the hot spring is situated in a mountainous area approximately 17 km north of Seulawah Agam volcano, part of the Bukit Barisan mountain range, and one of the active volcanic systems in Aceh (Syukri et al., 2014).

The rocks in the Ie Seu'um area are classified as Lam Teuba volcanic rocks (Qtvl) of Pleistocene age. They consist of volcanic deposits, including andesite, breccia, pumice, tuff, agglomerates, and ash flows interbedded with lahars. These volcanic units are partially overlain by young alluvium (Qh) composed of gravel, sand, and silt (Bennet et al., 1981).

In geophysics, several methods can be applied to investigate subsurface conditions in geothermal areas, with electrical resistivity being one of the most effective. This method is widely used in geothermal exploration because rock resistivity is highly sensitive to water content (Octaviani et al., 2018). The resistivity method involves injecting electrical current into the ground through two current electrodes, while the resulting potential difference is measured using two potential electrodes. This technique allows for the characterization of lithology and subsurface stratigraphy. The Wenner–Schlumberger configuration provides better resolution and penetration in both vertical and horizontal directions.

This study aims to identify the subsurface structure, through gephysical and geological investigations and evaluate the influence of hydrothermal activity's impact on rock characteristics within the geothermal manifestation area of Ie Seu'um.

2. Methodology

This study was conducted using the electrical resistivity method, which characterizes subsurface conditions based on variations in electrical resistance. Field data were acquired with a MAEX612EM+ resistivity meter along four survey lines. Survey Lines 1 and 2 were each approximately 106.5 m long, with an electrode spacing of 1.5 m and 72 electrodes. Lines 1 and 2 are located directly within the main hydrothermal manifestation area Ie Seuum, which geologically lies in an active tectonic zone dominted by quaternary volcanic rocks of the Lam Teuba Formation, partially covered by young alluvial deposits. In this area, the Seulimeum Fault serves as the main pathway for hidrothermal fluids to the surface, giving rise to manifestations such as the Ie Seuum hot springs. Survey Lines 3 and 4 were each about 210 m long, with an electrode spacing of 3 m and 72 electrodes. These lines were positioned 3.5 km from the Ie Seu'um geothermal manifestation, in hilly terrain with relatively dense vegetation cover. Geologically, this area consists of Quarternary volcanic rocks of the Lam Teuba Formation, partially covered by young alluvial deposits, but no surface geothermal manifestations are observed. Lines 3 and 4 are thus considered as the non-hydrothermal area. The presence of weathered volcanic rocks and alluvial accumulation make lines 3 and 4 suitable as a comparison area to investigate subsurface conditions outside the direct influence of the Ie Seuum hydrothermal system.

The field measurements produced apparent resistivity values, which were subsequently processed through inversion using the Res2Dinv software to generate accurate 2D resistivity models.

3. Result and Discussion

The inversion modeling produced 2D resistivity profiles for all four survey lines. Figure 3 presents the inversion result for Line 1, where the survey started in the north and ended in the south. The profile shows a low-resistivity zone ranging from 1 to 30.8 Ω·m, distributed at depths of approximately 0–12 m. This zone is interpreted as a rock layer influenced by hot fluids, likely representing the outflow pathway of geothermal fluids from the subsurface system. The presence of this conductive zone provides strong evidence of active hydrothermal processes beneath the study area.

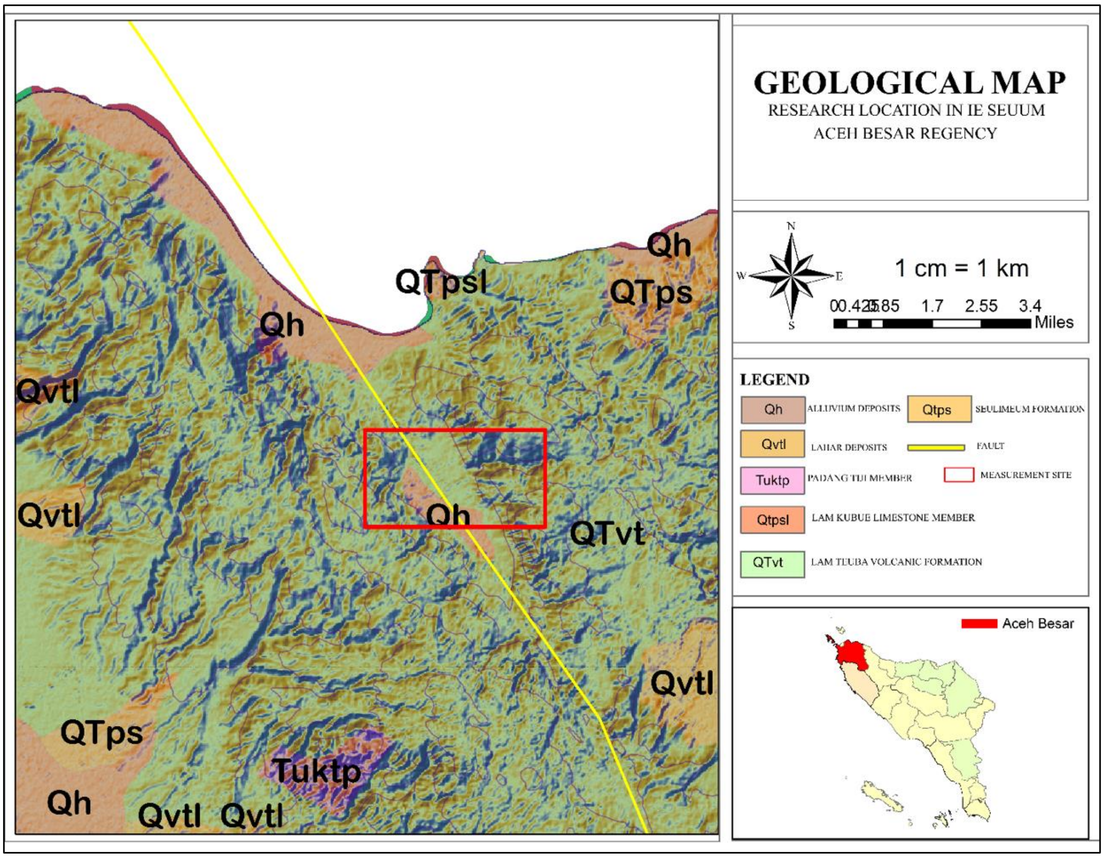

Fig. 1. Geological map of the Research Location, Ie Seuum Village, Mesjid Raya District, Aceh Besar Regency

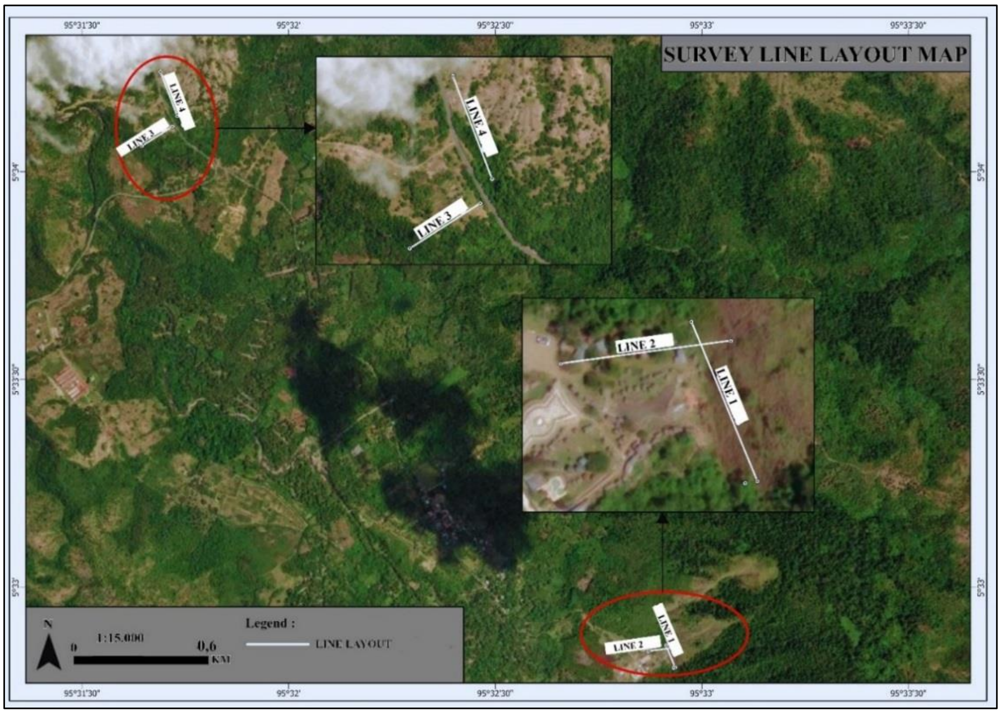

Fig. 2. Survey line map with 4 lines in Ie Seuum, Lines 1-2 are at the geothermal manifestation, while lines 3-4 are outside the geothermal manifestation.

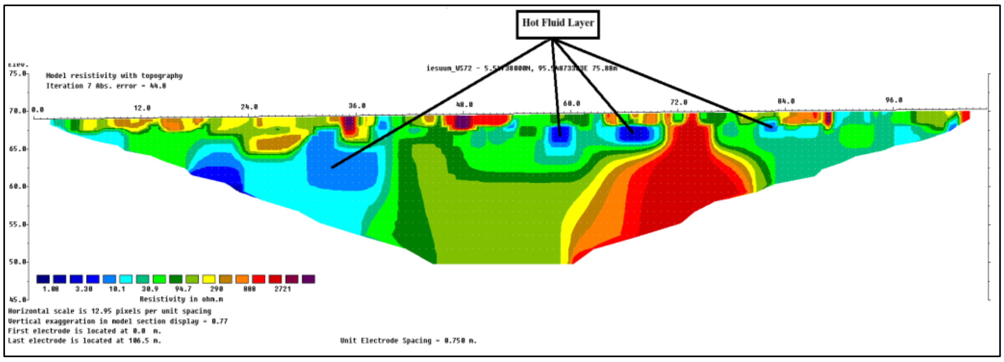

Fig. 3. 2D subsurface resistivity cross-section of survey line 1.

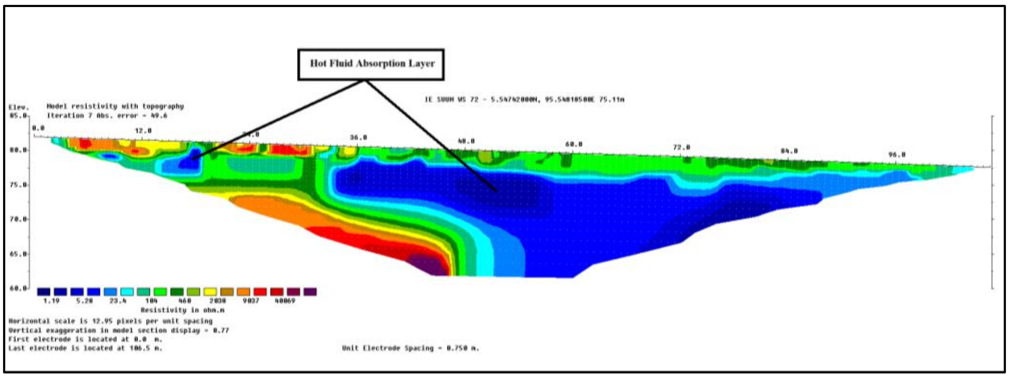

Fig. 4. 2D subsurface resistivity cross-section of survey line 2.

Survey Line 2 begins in an area of relatively higher topography and descends toward a more gently sloping area at the lower end. This line is located at a higher elevation than the other survey lines. The inversion result, shown in Figure 4, indicates the presence of a low-resistivity zone (1.19–64 Ω·m) distributed at depths of 0-19 m, between the horizontal distances of 36–96 m along the line. This conductive zone is interpreted as a subsurface layer influenced by the flow and absorption of fluids geothermal fluids, namely hot water and steam circulating through fractures and pore spaces of the rocks, which serve as the main medium for heat transfer from the resorvoir to the surface.

Survey Line 3 is located approximately 3.5 km from the primary hot spring source of Ie Seu'um and is oriented north–south. This line was used to validate the condition of rocks affected and unaffected by the subsurface geothermal system within the same geological setting. The inversion result, shown in Figure 5, reveals a central zone with very low resistivity values (0.1–9 Ω·m) distributed at depths of 0-8 m. This zone is interpreted as volcanic rocks weathered by meteoric water infiltration rather than geothermal fluid flow. The lack of surface manifestations or hydrothermal features indicates the absence of geothermal dispersion in this area.

Survey Line 4 is oriented east–west and intersects with Line 3, providing an additional geological perspective on subssurface lithological and structural distribution. This orientation allows for more comprehensive lateral mapping of resistivity variations in relation to both rock types and potential fault zones. The inversion result, shown in Figure 6, reveals a low-resistivity zone (1.2–14 Ωm) distributed at depths of 0-10 m. This zone is interpreted as a layer of weathered volcanic rock or or unsaturated material in the vadose zone, inferred from its shallow occurrence and resistivity range, and is more likely related to meteoric water infiltration rather than geothermal fluids. The absence of characteristic signatures such as fracture-controlled conductive or hydrothermal alteration zone indicates that no active hot fluids pathways are present. Overall, the resistivty distribution along this line support the interpretation that there is no active geothermal system beneath the surveyed area.

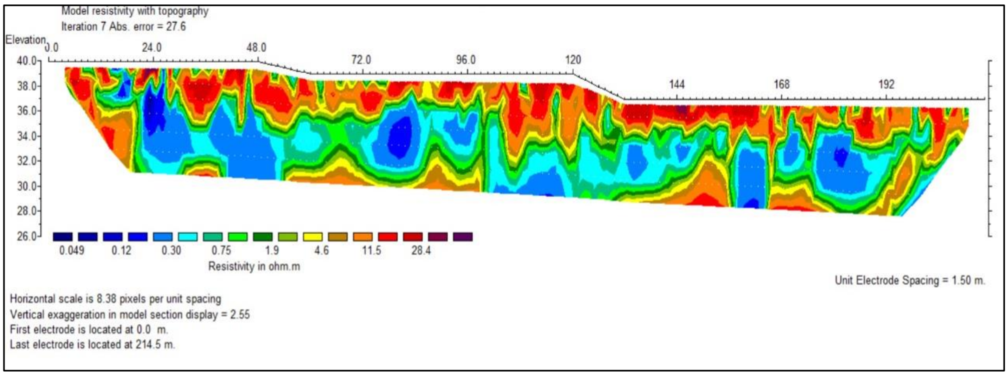

Fig. 5. 2D subsurface resistivity cross-section of survey line 3.

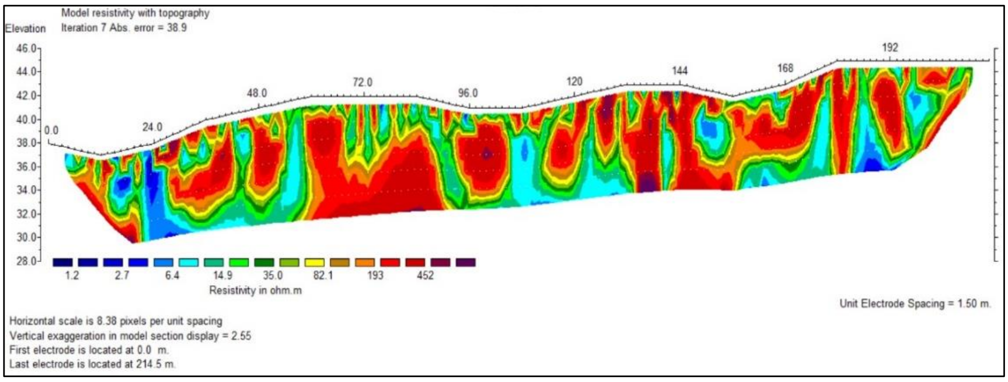

Fig. 6. 2D subsurface resistivity cross-section of survey line 4.

In this study, the research area was divided into 2 zone. Zone 1, consisting of survey lines 1 and 2, which are located close to the Ie Seuum geothermal area, and zone 2, consisting of survey lines 3 and 4, which are situated farther from the Ie Seuum geothermal area. Based on the results, zone 1 directly influenced by hydrothermal flow, and zone 2, unaffected by hydrothermal activity, exhibit distinct differences in rock physical properties. In general, Zone 1 displays a much wider resistivity range of 0–5000 Ω·m compared to Zone 2, which ranges only from 0–600 Ω·m. Zone 1 consists of volcanic rocks and more complex layers directly impacted by the active hydrothermal system, whereas Zone 2 comprises softer alluvium influenced by meteoric water (infiltrated rainwater) rather than geothermal fluids. These findings highlight the significant role of hot fluid interaction in altering rock characteristics and demonstrate that resistivity is a particularly effective geophysical method for identifying such features.

4. Conclusion

This study successfully identified subsurface rock alteration in the Ie Seu'um geothermal manifestation area by applying the electrical resistivity method to zones affected and unaffected by hydrothermal fluid flow. Zone 1, directly influenced by hydrothermal activity, exhibited a wider resistivity range of 0-5000 Ω.m, whereas Zone 2, which is unaffected by hydrothermal flow and showed a narrower resistivity range of 0-600 Ω.m. These contrasts demonstrate subsurface alteration between the two zones, confirming the significant effectiveness of resistivity analysis in detecting geothermal-related rock characteristics.

5. Acknowledgements

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