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RESEARCH ARTICLE

Application of Geoelectric Method for Groundwater Exploration: Comparative Study of Wenner-Alpha and Wenner-Schlumberger Configurations in Way Manak, Tanggamus

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Abstract. Groundwater is an important resource that needs to be managed sustainably, especially in areas with high dependence on groundwater such as Way Manak Village, Tanggamus Regency. This study aims to identify and map the distribution of aquifer layers in the Hulusimpang Formation using the Wenner-Alpha and Wenner-Schlumberger geoelectric resistivity configurations. Data acquisition was carried out on two intersecting lines of 235 meters with a distance between electrodes of 5 meters, and one vertical sounding point (VES). Data were processed using RES2DINV and IPI2Win software with a final RMS error value of 1.22-6.6%. The modeling results indicate a low resistivity zone (approximately 8-22 Ωm) at a depth of 1-19 m which is interpreted as a shallow aquifer layer, associated with the tuffaceous sandstone and sandy tuff lithology of the Hulusimpang Formation. The Wenner-Schlumberger configuration shows better penetration capability and depth resolution than Wenner-Alpha, making it more effective in detecting vertical and lateral resistivity variations. Overall, the combination of these two configurations provides a more comprehensive picture of subsurface hydrogeology, and the results can be used as a reference in planning groundwater resource management in the research area. The comparative interpretation also shows that integrating laterally sensitive and vertically penetrating arrays reduces ambiguity in distinguishing shallow saturated zones from lithological contrasts.

Abstrak. Air tanah merupakan sumber daya penting yang perlu dikelola secara berkelanjutan, terutama di wilayah dengan ketergantungan tinggi terhadap air bawah permukaan seperti Desa Way Manak, Kabupaten Tanggamus. Penelitian ini bertujuan untuk mengidentifikasi dan memetakan sebaran lapisan akuifer pada Formasi Hulusimpang menggunakan metode geolistrik resistivitas konfigurasi Wenner-Alpha dan Wenner-Schlumberger. Akuisisi data dilakukan pada dua lintasan bersilangan sepanjang 235 meter dengan jarak antar elektroda 5 meter, serta satu titik sounding vertikal (VES). Data diolah menggunakan perangkat lunak RES2DINV dan IPI2Win dengan nilai galat RMS akhir 1,22-6,6%. Hasil pemodelan menunjukkan adanya zona resistivitas rendah (sekitar 8-22 Ωm) pada kedalaman 1-19 m yang diinterpretasikan sebagai lapisan akuifer dangkal, berasosiasi dengan litologi batupasir tufan dan tufa pasiran Formasi Hulusimpang. Konfigurasi Wenner-Schlumberger menunjukkan kemampuan penetrasi dan resolusi kedalaman yang lebih baik dibandingkan Wenner-Alpha, sehingga lebih efektif dalam mendeteksi variasi resistivitas vertikal dan lateral. Secara keseluruhan, kombinasi kedua konfigurasi ini memberikan gambaran hidrogeologi bawah permukaan yang lebih komprehensif, dan hasilnya dapat menjadi acuan dalam perencanaan pengelolaan sumber daya air tanah di wilayah penelitian. Interpretasi komparatif juga menunjukkan bahwa integrasi konfigurasi yang sensitif secara lateral dan memiliki penetrasi vertikal lebih baik dapat mengurangi ambiguitas dalam membedakan zona jenuh air dangkal dari kontras litologi.

1. Introduction

Groundwater is a natural resource that plays a vital role in supporting human life, especially in regions with high dependence on subsurface water sources. The increasing need for clean water due to population growth and agricultural activities demands accurate mapping of aquifer potential for sustainable groundwater management. The electrical resistivity method is a geophysical technique widely used in groundwater exploration because it provides information on subsurface resistivity distribution related to water content, porosity, and rock type (Telford et al., 1990). The basic principle of this method is to inject an electric current through current electrodes and measure the potential difference through potential electrodes to obtain an apparent resistivity value, which is then processed into a true subsurface resistivity model.

Various previous studies have demonstrated the effectiveness of the geoelectric method in identifying aquifer layers, but its interpretation is highly influenced by the type of electrode configuration and local geological conditions. Research by Dahlin and Zhou (2004) indicates that the Wenner-Schlumberger configuration has good sensitivity to lateral and vertical resistivity variations, while the Wenner-Alpha configuration provides stable data distribution with relatively high vertical resolution. However, most studies only use one type of electrode configuration, which limits spatial resolution and interpretation uncertainty (Loke et al., 2003). This situation highlights a research gap in the use of combined configurations to improve the accuracy of subsurface resistivity models, particularly in the context of aquifer identification in areas with complex geological conditions. This research aims to identify and map the distribution of aquifer layers in Way Manak Village, Pugung District, Tanggamus Regency, Lampung Province, using the resistivity geoelectric method with Wenner-Alpha and Wenner-Schlumberger configurations. Measurements were taken at two intersecting cross-sections and one Vertical Electrical Sounding (VES) point on one of the cross-sections to obtain more detailed vertical information. The results of this research are expected to provide an overview of the local hydrogeological conditions and serve as a reference for more sustainable groundwater resource management in the region. Geophysical methods have proven effective in identifying geological characteristics and groundwater potential, as demonstrated by the research of Darmawan et al. (2025) and Rustadi and Rananda (2020). Therefore, this study aims to identify aquifers in the Pugung area.

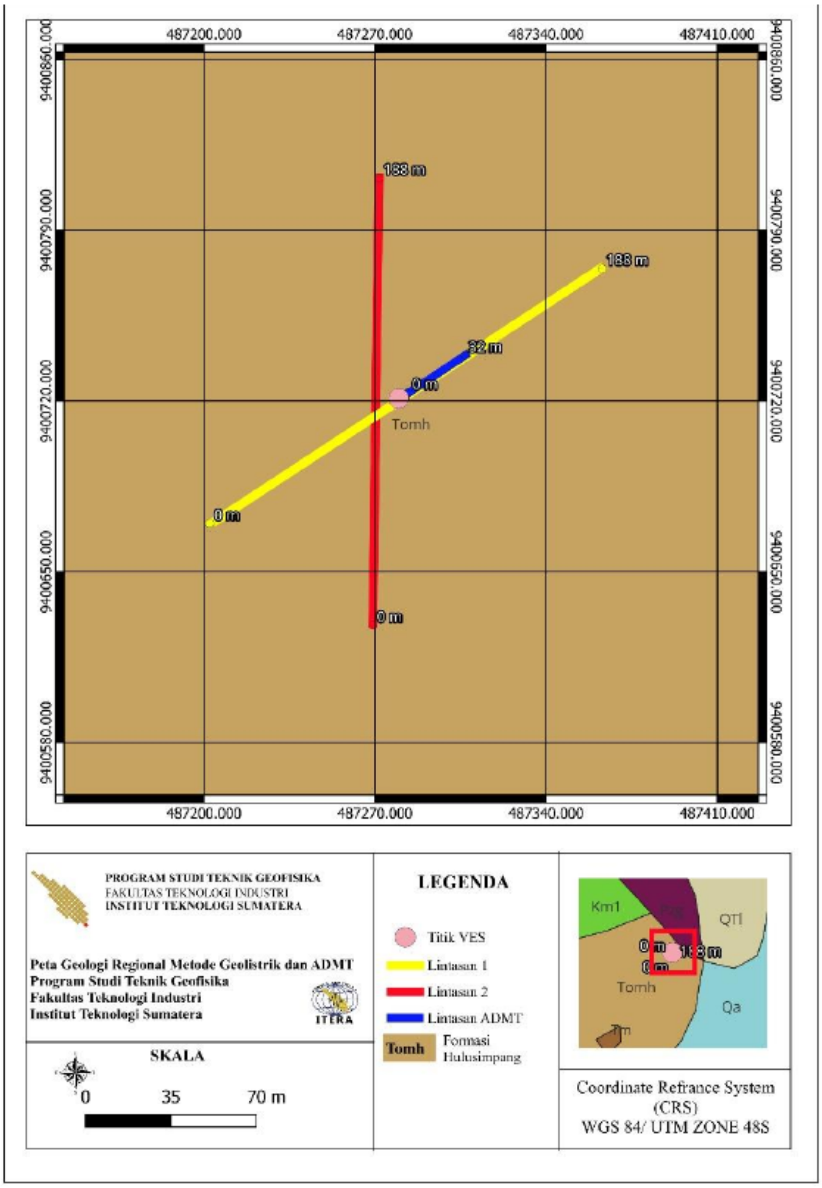

Figure 1. Regional Geological Map of Kotaagung (modified from Amin et al., 1993), with the red box indicating the study location.

The novelty of this study lies not only in applying geoelectrical measurements to a local groundwater problem, but also in evaluating how two commonly used electrode configurations respond to the same hydrogeological target. This comparison is important because low resistivity anomalies may reflect either water saturation, clay-rich material, weathered volcanic products, or a combination of these factors. A single configuration can therefore produce an interpretation that is geometrically plausible but geologically underconstrained. By comparing Wenner-Alpha and Wenner-Schlumberger results along intersecting lines, this study attempts to strengthen the interpretation through pattern consistency, depth continuity, and agreement with the mapped Hulusimpang lithology.

The research area consists of four distinct formation units: Alluvial, Hulusimpang Formation, Gunung Kasih Complex, and Lampung Formation. The metamorphic rocks of the Mount Kasih Complex (Pzg) are interpreted as the oldest geological unit on the

Kota Agung sheet, consisting of pelitic schist with a little gneiss. Additionally, there is the Sidodadi Quartzite Unit, which contains quartzite with schist-sericite and quartzite interlayers, and the Jundeng Migmatite Unit, which is composed of granitoids, schists, and gneisses intruded by granite veins.

The Hulusimpang Formation (Tomh) is Late Oligocene-Early Miocene in age and was deposited in a shallow terrestrial-marine transitional environment. It consists of altered, quartz-veined, and sulfide mineral-bearing volcanic breccia, lava, and andesitic-basaltic tuff. The Lampung Formation (QTl), of Plio-Pleistocene age, is composed of pumiceous tuff, tuffaceous sandstone, with occasional tuffite interbeds formed in terrestrial to fluvial environments. Topographic variations of up to 40 meters above sea level have led to the accumulation of alluvial deposits in the area, consisting of gravel, boulders, sand, silt, and clay (Amin et al., 1993).

2. Data and Methods

This research utilizes geoelectric data obtained from field surveys in Way Manak, Tanggamus Regency, Lampung Province, with the aim of identifying aquifer layers based on subsurface resistivity characteristics. Data acquisition was conducted on June 19, 2025, using 1D and 2D geoelectric methods. The data acquisition design was based on field conditions and site accessibility, without considering topographic variations due to the lack of detailed elevation data along the measurement traverse. Two measurement lines were placed in areas with varying geological characteristics to obtain representative data coverage of subsurface conditions, as shown in Figure 2 below.

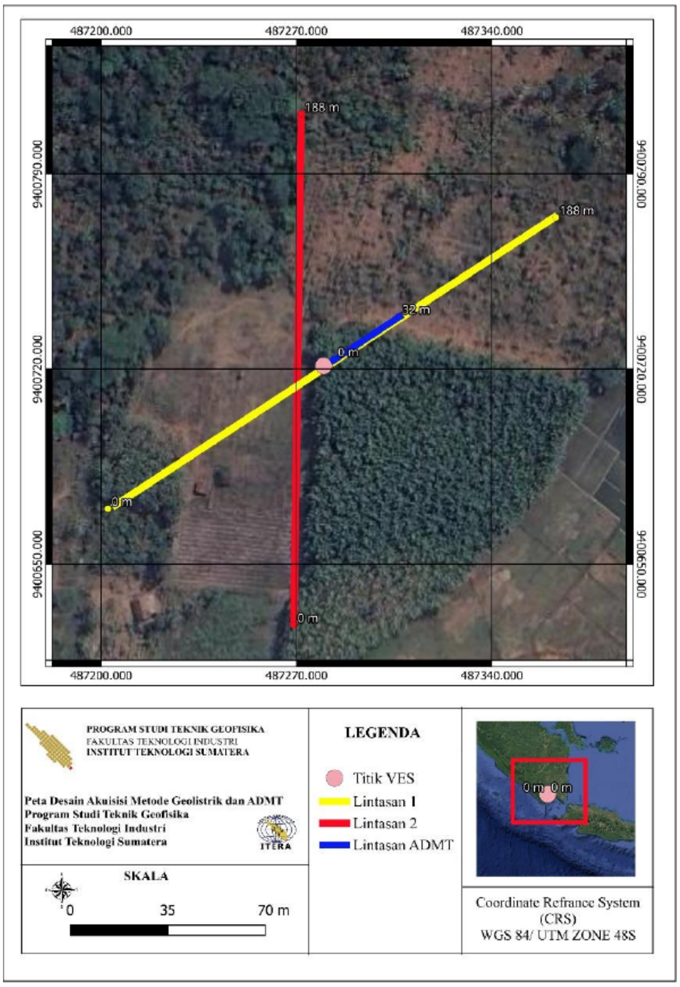

Figure 2. The measurement point locations used in the research

2D measurements were conducted using the Wenner-Alpha and Wenner-Schlumberger configurations, each consisting of 48 electrodes with a spacing of 5 meters, resulting in a traverse length of approximately 235 meters. The two lines intersect to obtain resistivity information both vertically and laterally. The Wenner-Alpha configuration was chosen because it has good vertical sensitivity to horizontal layers, while the Wenner-Schlumberger is used to detect more complex lateral variations (Loke, 2015). The apparent resistivity value (ρa) is calculated using the equation:

$$\rho a = K(V/I) \qquad (1)$$

where K is a geometric factor that depends on the distance between the electrodes (Telford et al., 1990).

The data from 1D measurements were processed using IPI2Win software to obtain an initial overview of the subsurface vertical resistivity. Next, 2D data processing was performed using RES2DINV for Windows, which implements a constrained least-squares inversion algorithm (Loke and Barker, 1996). The inversion process is performed for up to five iterations or until the final RMS error value between 3% and 6% is reached, indicating a good level of model convergence.

The 1D sounding result was used as a vertical control for interpreting the 2D inversion sections. Although 1D modeling simplifies the subsurface into layered units, it provides a useful first-order estimate of the resistivity-depth relationship. The 2D profiles were then used to evaluate whether the low-resistivity interval identified in the sounding also extends laterally along the measurement lines. This workflow is important because groundwater targets are rarely expressed only as a single vertical layer; in volcanic and volcaniclastic terrains, aquifer potential is commonly controlled by lateral changes in grain size, degree of weathering, fracture intensity, and clay content.

The inversion results are presented in three pseudo-sections: measured apparent resistivity, calculated apparent resistivity, and inversion model resistivity. These three results illustrate the distribution of subsurface resistivity both vertically and laterally. Areas with low resistivity (5-50 Ω·m) are interpreted as water-saturated layers or clay materials, while high resistivity values indicate impermeable layers or dense volcanic rocks (Reynolds, 2011).

It should be noted that at the data processing stage, elevation information was not included in the model because detailed topographic data was not available along the measurement track. Thus, the 2D resistivity profile is presented under the assumption of a flat field, which may lead to simplifications compared to the actual geological conditions.

Validation of the results was performed by comparing two intersecting profiles to assess the consistency of the subsurface resistivity distribution. Relatively similar resistivity patterns in the intersection area indicate model consistency and the reliability of the inversion results. Overall, the combination of field data acquisition design, geological interpretation of the Hulusimpang Formation, and data processing using RES2DINV resulted in a systematic and reliable analysis for identifying aquifer layers in Way Manak, Tanggamus Regency.

3. Results and Discussion

3.1 Results

1D Geoelectric Modeling

The 1D model separates the shallow subsurface into three resistivity units. The uppermost unit, with a resistivity of 81.4 Ωm and a thickness of 1.98 m, is interpreted as relatively dry or compacted topsoil. The second unit, with a lower resistivity of 22.4 Ωm and extending to a depth of 13.8 m, is the most important hydrogeological interval because its resistivity falls within the range commonly associated with water-bearing sandy tuff or saturated weathered material. The third unit has a higher resistivity of 97.2 Ωm and is interpreted as more compact volcanic material, possibly acting as a lower boundary or less permeable layer for the shallow groundwater system.

The Wenner-Alpha profiles show a laterally continuous low-resistivity band across both lines, particularly in the shallow to intermediate depth interval. In Line 1, the low resistivity zone is concentrated between approximately 5.10 and 15.8 m, while Line 2 shows a similar conductive interval beginning closer to the surface. The consistency of this feature across both lines indicates that the anomaly is unlikely to be a local inversion artifact. Instead, it suggests a continuous shallow saturated zone or a water-bearing weathered tuff layer within the Hulusimpang Formation.

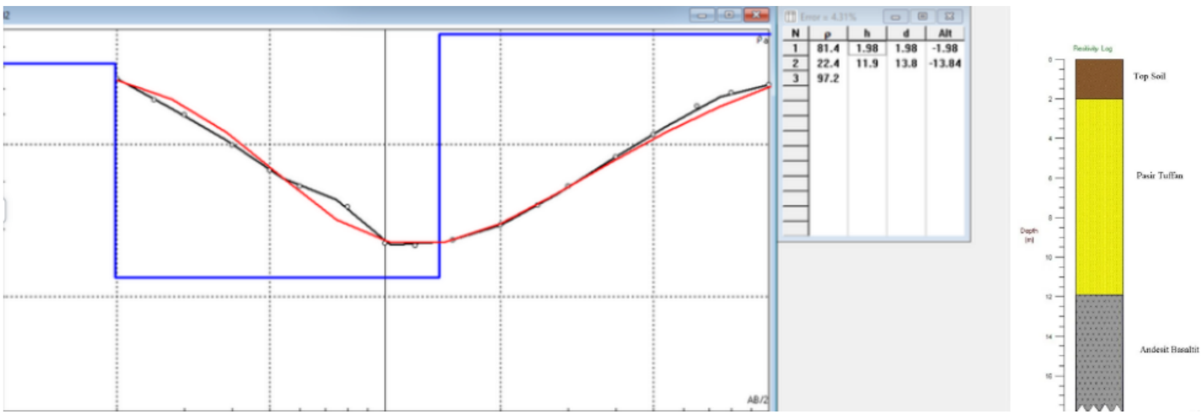

Figure 3. Results of 1D Geoelectric Modeling

Table 1. Resistivity 1D model

No	Resistivity Value	Thickness (h)	Depth (d)	Alt
1.	81.4	1.98	1.98	-1.98
2.	22.4	11.9	13.8	-13
3.	97.2			

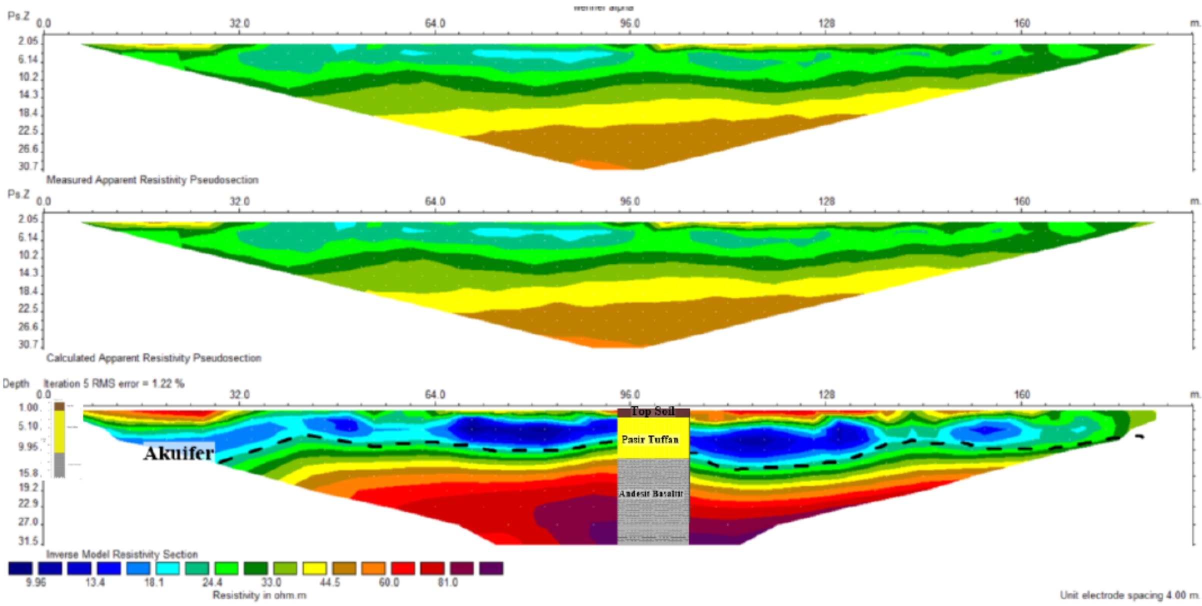

Figure 4. Wenner-Alpha Line 1

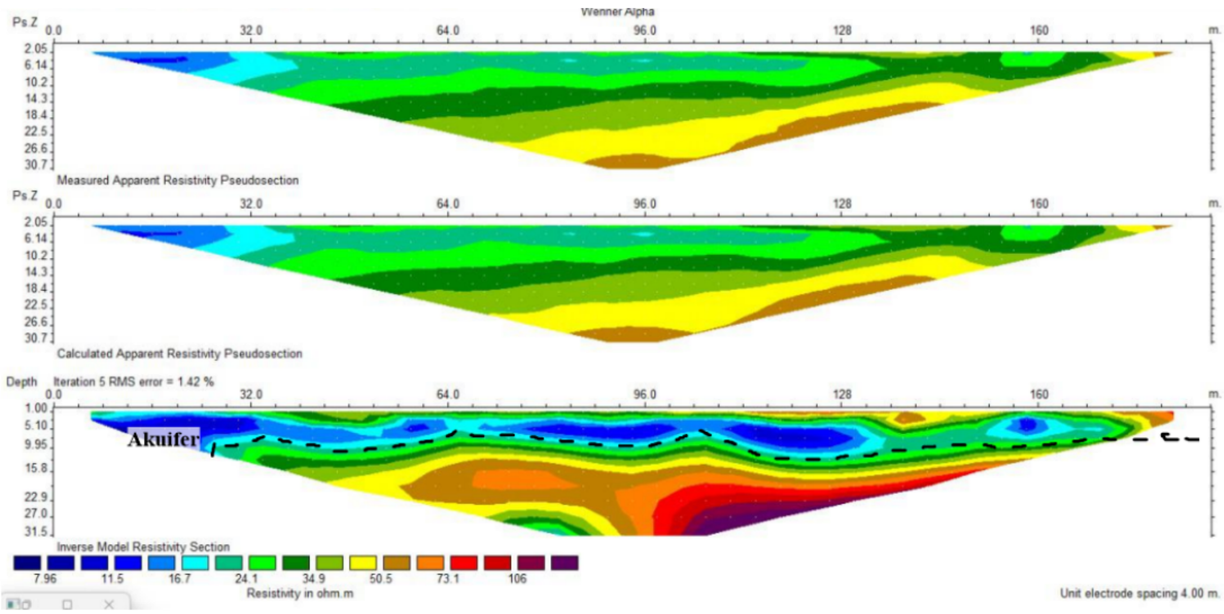

Figure 5. Wenner-Alpha Line 2

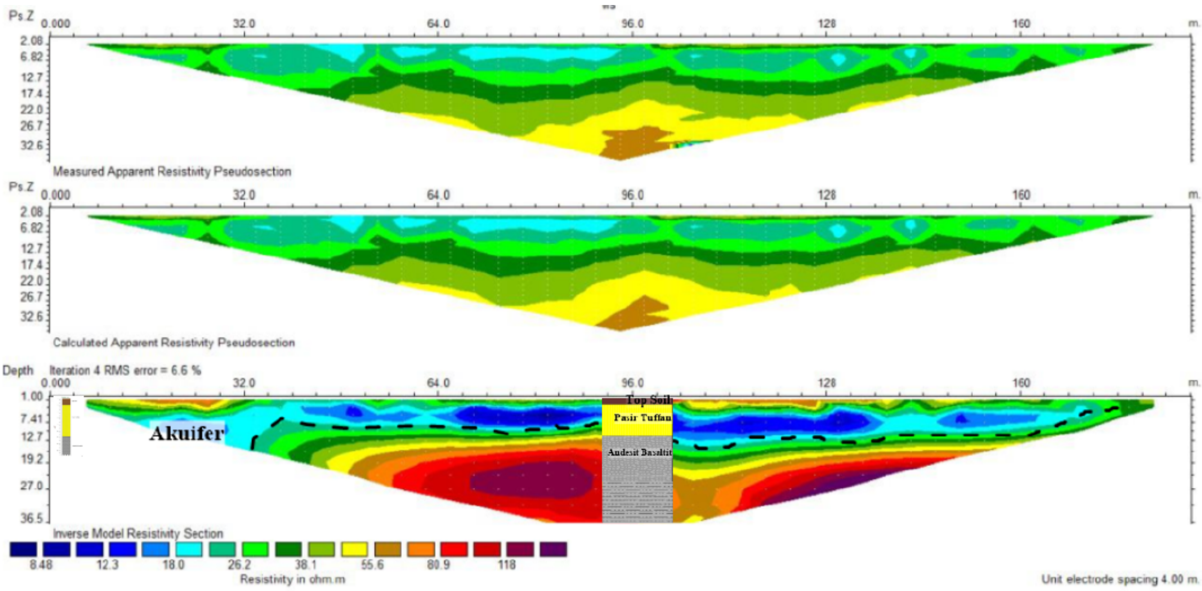

Figure 6. Wenner-Schlumberger Line 1

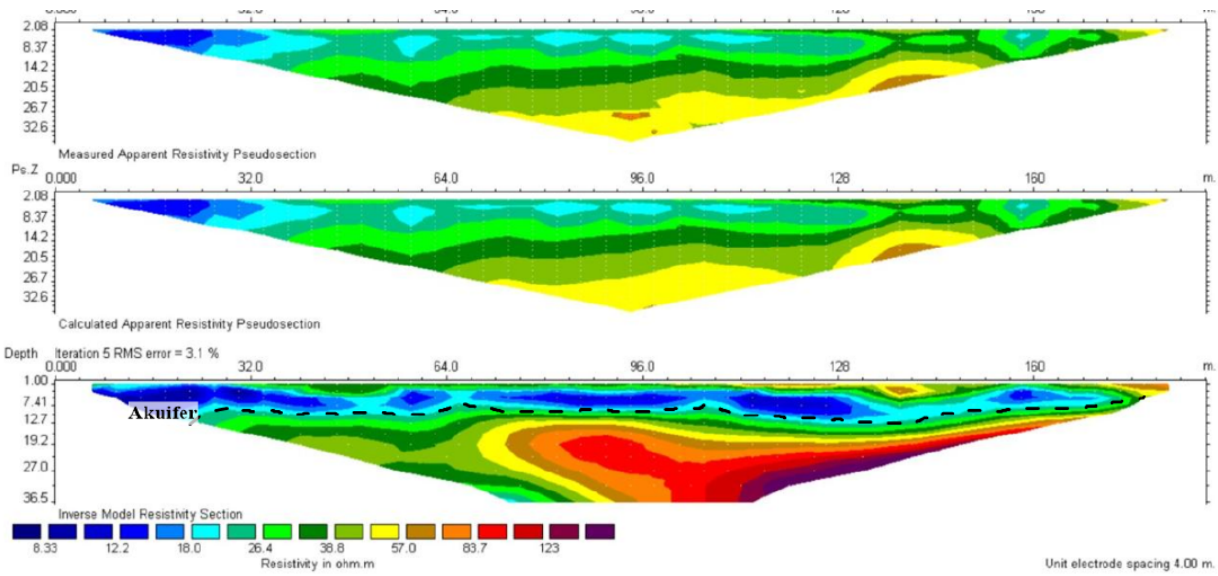

Figure 7. Wenner-Schlumberger Line 2

The Wenner-Schlumberger profiles preserve the same low-resistivity pattern but image it with clearer vertical development. Line 1 identifies the aquifer-related zone from about 1.5 to 19.2 m, while Line 2 images a shallower conductive interval from approximately 1 to 12.7 m. This difference suggests that the aquifer geometry is not uniform along the survey area. The saturated layer appears to thicken or deepen along Line 1, whereas Line 2 shows a shallower and more laterally constrained conductive feature. Such geometry is reasonable in a volcaniclastic setting where weathering intensity, sediment sorting, and local permeability may vary over short distances.

3.2 Discussion

The main interpretation problem in this study is separating the effect of groundwater saturation from the effect of lithology. In resistivity surveys, low resistivity does not automatically indicate groundwater, because clay-rich material, intense weathering, and mineralized volcanic deposits can produce similar responses. For this reason, the anomaly was interpreted using three criteria: the resistivity range, the depth continuity between 1D and 2D results, and the geological context of the Hulusimpang Formation. The consistent appearance of low resistivity in the 1D model and in both 2D configurations strengthens the interpretation that the anomaly is related to a shallow saturated layer rather than a purely local lithological feature.

Resistivity modeling shows that the first layer is located at a depth of 0-1.98 meters with a resistivity of 81.4 Ωm and is interpreted as topsoil. Below this, the second layer appears at a depth range of 1.98-13.8 meters with a resistivity of 22.4 Ωm, indicating the characteristics of sandy tuff. The lower resistivity value in this layer indicates the presence of a shallow aquifer. This interpretation is supported by the expected behavior of tuffaceous sandstone and sandy tuff, where pore space and weathering can increase water storage while still maintaining enough permeability to behave differently from clay-rich material.

On Line 1 with the Wenner-Alpha configuration, the aquifer zone is visible at a depth of 5.10-15.8 meters with a resistivity value of 9.96-18.1 Ωm. A similar pattern appears on Line 2, where the conductive layer is located at a depth of 1 to approximately 15.8 meters with a resistivity of 7.96-16.7 Ωm. Both profiles show a resistivity pattern consistent with the characteristics of the Hulusimpang Formation: a more resistive surface layer, a middle layer with moderate-low resistivity, and a conductive zone at the bottom. The consistent low resistivity on both traverses supports the interpretation of a shallow aquifer that is laterally continuous. The low RMS error values (1.22% and 1.42%) confirm that the Wenner-Alpha model is quite reliable.

The Wenner-Alpha response is useful for identifying the lateral persistence of the shallow conductive layer. Because this configuration uses equal electrode spacing, it tends to produce stable responses for near-surface horizontal to gently undulating layers. In this study, that characteristic helps show that the aquifer-related anomaly is not restricted to a single point but extends along both measurement lines. However, the same stability can also make the deeper part of the section less sharply resolved, especially where the target changes rapidly with depth. Therefore, the Wenner-Alpha result is best used here as evidence for lateral continuity and shallow aquifer distribution.

Meanwhile, the Wenner-Schlumberger configuration shows a similar trend but with better depth resolution. On Line 1, the aquifer zone was identified at a depth of 1.5-19.2 meters with a resistivity of 8.48-18 Ωm, while Line 2 showed a water-saturated zone at a depth of 1-12.7 meters, which was clearly visible through the blue color gradation on the inversion profile. The two intersecting lines confirm the lateral connectivity of the low resistivity zone. This condition is consistent with the lithology of the Hulusimpang Formation, which is dominated by tuffaceous sandstone, silty sand, and silt. Although Schlumberger's first traverse had a higher RMS error (6.6%), the results are still relevant for comparison with the Wenner-Alpha configuration.

The Wenner-Schlumberger result adds an important vertical constraint to the interpretation. Its greater current-electrode separation allows deeper current penetration, so the geometry of the conductive layer can be observed more clearly at depth. The deeper low-resistivity interval on Line 1 suggests that groundwater potential may be better developed along this line than along Line 2, although this interpretation should be treated as a geophysical estimate rather than a direct hydraulic measurement. The difference between the two lines may reflect local variation in weathering thickness, fracture density, or the distribution of sandy tuff horizons that can store and transmit groundwater.

In general, this study aims to compare the ability of Wenner-Alpha and Wenner-Schlumberger in recognizing aquifer layers in Way Manak. Based on the modeling results, the Schlumberger configuration provides better vertical resolution and clearer resistivity contrast, making it more effective in heterogeneous lithological conditions. The resistivity range obtained (10-600 Ωm) can be grouped into three main layers: topsoil, a transition layer consisting of silty sand or altered tuff, and fractured volcanic rock at depths >25 meters. Resistivity <50 Ωm is associated with water-saturated layers, while values >200 Ωm reflect hard or non-porous rock.

The practical implication is that the shallow aquifer target in Way Manak should not be defined from one resistivity threshold alone. A more robust target zone is the interval where three conditions overlap: resistivity generally below 50 Ωm, continuity between the 1D and 2D models, and position within the expected weathered or sandy tuff facies of the Hulusimpang Formation. Based on these criteria, the most promising interval is broadly located between about 1 and 20 m depth. This depth range is shallow enough to be relevant for community-scale groundwater exploration, but it also means that the aquifer may be sensitive to seasonal recharge, surface contamination, and changes in land use.

This interpretation aligns with various previous studies. Kumalasari et al. (2025) found shallow aquifers at depths of 10-28 meters in Hajimena, while Malujung et al. (2022) reported very low resistivity (0.1-2.4 Ωm) in Kubu Raya due to the dominance of water-saturated clay. The findings of Bu'tu et al. (2024) using the Schlumberger configuration also indicate the presence of aquifers with low to medium resistivity (<100 Ωm). This pattern similarity reinforces the general conclusion that Schlumberger is more capable of capturing deeper aquifer layers than Wenner-Alpha. Physically, the performance difference between the two configurations is influenced by the current distribution pattern. Wenner-Alpha with uniform electrode spacing is more sensitive to horizontal variations at shallow depths, while Schlumberger with wider current electrode spacing allows for deeper current penetration. This is evident from its ability to map low resistivity zones up to >30 meters.

Compared with those studies, the aquifer interpreted in Way Manak appears relatively shallow and is associated with moderate to low resistivity rather than extremely low resistivity. This distinction is important because very low resistivity may indicate clay-dominated sediments with limited permeability, whereas the 8-22 Ωm range observed here can be consistent with sandy tuff or weathered volcaniclastic material containing groundwater. Therefore, the interpretation favors a shallow unconfined to semi-confined aquifer system rather than a thick clayey aquitard. Nevertheless, lithological confirmation remains necessary because resistivity alone cannot uniquely determine hydraulic conductivity.

Although the research findings are quite convincing, some limitations remain. The aquifer depth obtained has not yet been verified with drilling data, so it is still an estimate. Soil moisture conditions and seasonal variations can also affect resistivity values.

Therefore, future research is recommended to combine 2D/3D geoelectric methods, well logging, and hydrogeochemical analysis to provide a more comprehensive picture of the aquifer.

Another limitation is the absence of detailed topographic correction in the inversion model. The profiles were interpreted under a flat-surface assumption, whereas the field area has topographic variation and local drainage patterns that may influence groundwater flow. Topography can affect apparent resistivity distribution and may shift the apparent depth of anomalies in inversion results. Future surveys should therefore include elevation control, repeat measurements in different seasons, and calibration with borehole or well data. These additional data would make it possible to distinguish between saturated permeable layers, clay-rich horizons, and weathered but relatively dry volcanic units.

Overall, this research confirms that the choice of electrode configuration is crucial for the quality of geoelectric interpretation. Wenner-Schlumberger proved superior for medium-to-deep target depths, while Wenner-Alpha provided a good picture of shallow layers. The combination of both methods can produce a more complete hydrogeological map in complex geological areas like Way Manak.

4. Conclusions

This study demonstrates that the integration of 1D VES and 2D resistivity imaging can improve the interpretation of shallow groundwater potential in the Hulusimpang Formation at Way Manak. The 1D model indicates a low-resistivity layer of 22.4 Ωm between 1.98 and 13.8 m depth, which is interpreted as sandy tuff or saturated weathered material. The 2D profiles confirm that this conductive interval is not isolated, but extends laterally across the survey area. In the Wenner-Alpha results, the aquifer-related zone occurs at approximately 5.10-15.8 m in Line 1 and 1-15.8 m in Line 2. In the Wenner-Schlumberger results, the same target is imaged at about 1.5-19.0 m in Line 1 and 1-12.7 m in Line 2. These results indicate that the study area contains a shallow groundwater system, generally within the upper 20 m of the subsurface. The Wenner-Alpha configuration is useful for recognizing shallow lateral continuity, whereas the Wenner-Schlumberger configuration provides clearer vertical resolution and deeper penetration. The combined use of both configurations therefore produces a more defensible aquifer interpretation than either configuration alone. However, the interpretation should be verified through borehole data, groundwater level measurements, and seasonal repeat surveys before being used as the sole basis for groundwater development planning.

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Data Availability Statement

The data used and analyzed in this study were obtained from geoelectrical survey measurements conducted in the Hulusimpang Formation area. These data are not publicly available as they are part of an internal research archive and are subject to institutional policies regarding the use and distribution of primary data. However, the raw data and processed results may be obtained from the corresponding author upon reasonable request for verification or further research purposes.

Declaration of Competing Interest

The authors state that this research was conducted independently without any influence from any party. There are no financial or personal conflicts of interest that could affect the implementation, results, or preparation of this article. All scientific decisions are made based on academic consideration and research integrity to ensure the objectivity and reliability of the reported results.

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