ISSN: 2963-2536 (media online)

Proceedings of Malikussaleh International Conference on Multidisciplinary Studies (MICoMS)
Organized by center of Excellence of Technology Natural Polymer and Recycle Plastics

International Conference Proceedings 00001 (2024) DOI: https://doi.org/10.29103/micoms.v4.2024

Determination of Aquifer Depths in Muara Batu and Dewantara Sub-districts, North Aceh Regency, Using Vertical Electrical Sounding (VES)

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Abstract. This study aims to determine the depth of aquifer layers in Muara Batu and Dewantara sub-districts, North Aceh Regency, Indonesia. The investigation was conducted at five location points (NA1, NA2, NA3, NA4, and NA5), each with a 600 m spread. Data collection at these points was carried out using the Vertical Electrical Sounding (VES) method with a Schlumberger configuration, utilizing the SuperSting R8/IP Resistivimeter. The data processing results produced resistivity cross-sections of the rock layers down to a depth of 150 m. Based on the cross-sections, the aquifer layers exhibit low resistivity values (<13.5 Ωm), consisting of sand, a mixture of sand and gravel, calcareous sandstone, and sandstone. The depths of potential aquifer layers at each measurement point are as follows: 35.9–150 m at NA1, 23.6–150 m at NA2, 54.5–150 m at NA3, 28.5–101 m at NA4, and 52.8–150 m at NA5. Points NA1, NA2, NA3, and NA4 show the presence of water-saturated layers starting at a shallow depth of 1.5 m. In contrast, NA5, located in a hilly area with complex geological conditions, has more resistive layers and limited groundwater potential compared to the other points.

Keyword: Vertical Electrical Sounding, Aquifer, Groundwater, Muara Batu, Dewantara

1. Introduction

Water is one of the basic necessities of life, both individually and socially. Water plays a primary role in human body metabolism, so the quality of drinking water must be suitable for consumption. Additionally, the use of water resources for industry, infrastructure development, agriculture, and other purposes must also meet raw water quality standards. In providing raw water in a region, both quantity and quality play an essential role in determining the suitability of water for various uses. Unclean and chalky water conditions are very common in North Aceh, particularly in the sub-districts of Muara Batu and Dewantara. Therefore, studying the distribution and characterization of aquifers is crucial as a foundation for sustainable development in this region.

One of the primary water sources on Earth is groundwater, which is found in the pores of subsurface layers (Fitts, 2002). Additionally, groundwater is one of the safest water sources as it has natural protection against pollution. However, the distribution of groundwater beneath the surface is not uniform (Price, 2013). Groundwater can be identified based on the distribution of permeable and impermeable layers below the surface (Kirsch, 2006). Groundwater conditions are associated with saturated rock layers that can store and transmit water, known as aquifers (Younger, 2007).

One of the geophysical methods that can be used to identify groundwater is the 1D geoelectric method or Vertical Electrical Sounding (VES). This method measures the resistivity of rocks vertically at a single location and can help detect the presence of aquifer layers beneath the surface (Rusydy et al., 2020). The geoelectric method has been successfully applied in various studies, such as groundwater identification (Darisma et al., 2020), aquifer layer identification (Syafrizal et al., 2022), and geotechnical investigations (Yanis et al., 2022). In this study, the VES method with the Schlumberger array was used to obtain a deep subsurface profile (Hamzah et al., 2007). This configuration involves four electrodes arranged in a straight line, where two current electrodes (C1 and C2) are used to inject current into the ground, while two potential electrodes (P1 and P2) are used to measure the voltage generated by the current flow. The Schlumberger array is highly sensitive to vertical resistivity changes, allowing for the identification of non-homogeneous subsurface layers based on changes in potential electrodes. This method can map the subsurface conditions with varying resistivity values. Differences in resistivity reflect different materials beneath the surface (Suryadi et al., 2018).

It is hoped that the results of this study will provide useful information in identifying potential locations for groundwater drilling, which is necessary to meet the growing demand for clean water due to population growth, agriculture, and domestic needs.

2. Geology of Research Area

Muara Batu and Dewantara sub-district based on the geology of the Lhokseumawe quadrangle (Keats et al., 1981) are areas consisting of the Alluvium (Qh) and Idi Formation (Qpi). The Idi Formation known as terrace deposits is divided into 4 different areas namely Samalanga, Peudada, Krueng Jambo Aye, and Lhokseumawe. The research area is included in the Lhokseumawe area which consists of reefal limestones, gravels, sandstones, and calcareous mudstones.

The Idi Formation in the Lhokseumawe area is a hilly area. This formation is covered by Alluvium and under another by the Julu Rayeu Formation. While Alluvium consists of gravels, sands, and clays. Alluvium is generally found in the lowlands along the coastline where the NA1 point of observation was conducted. The other semi-consolidated material also presents as a regolith layer above the carbonate group. The location points included in the Idi Formation are NA2, NA3, NA4, and NA5.

The variation of lithological presence in Idi Formation is based on complex different depositional environments that consist of terrestrial and marine zones during quaternary periods such as fluvial, litoral-marine, and marine-litoral and litoral-fluvial environments. The research location is generally located in a fluvial to littoral environment based on conglomerate, calcrite and reefal limestone presence.

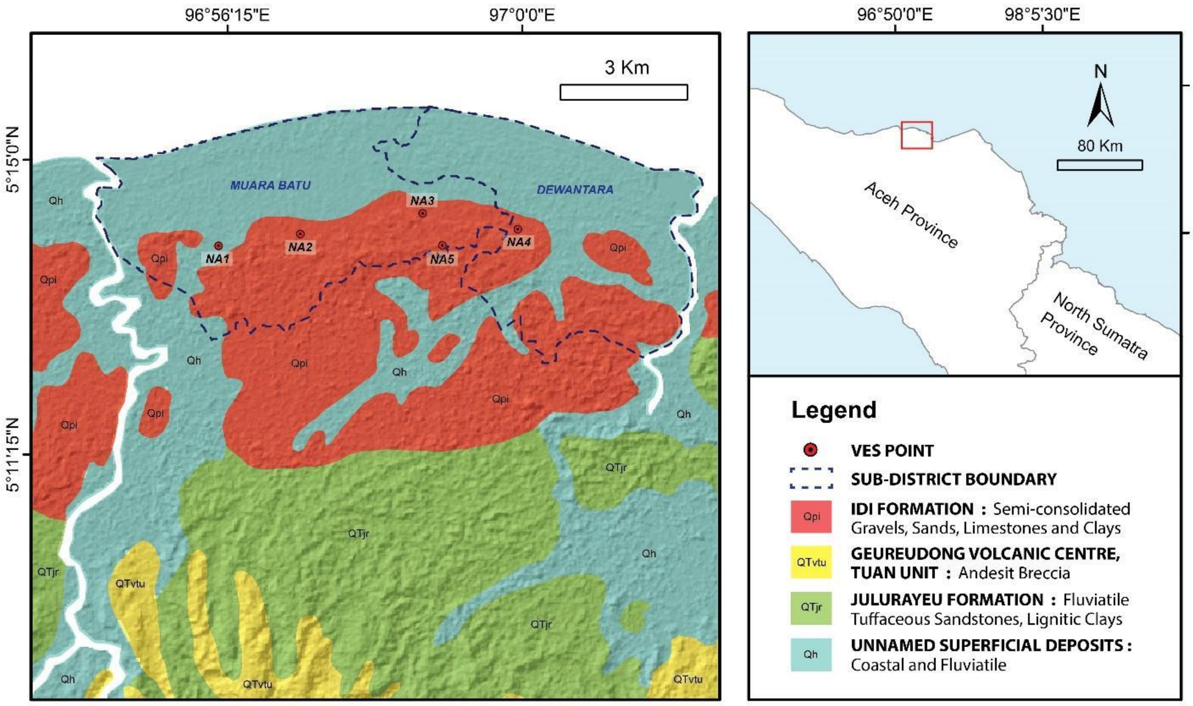

Figure. 1. Geological map of the research area shows that the research location points are in Idi Formation, and Alluvium (Keats et al., 1981).

3. Methods

Groundwater investigations were carried out at 5 location points in Muara Batu District (4 points) and Dewantara (1 point). The research point was chosen at a location around which there are drilled wells. These points are NA1 (Paloh Raya), NA2 (Pinto Makmur), NA3 (Reuleut Timue), NA4 (Paloh Igeuh), and NA5 (Reuleut Timue).
Data collection was carried out using the Vertical Electrical Sounding (VES) Schlumberger Array method. VES is an electrical resistivity method using direct current (DC) by measuring the potential difference (Hamzah et al., 2007). The data acquisition process requires two electrodes C1 and C2 which are used to inject current and two other electrodes P1 and P2 to measure the potential difference. Apparent resistivity ρ_a calculated based on the current I and potential difference ΔV with the geometric factor K. In the Schlumberger Array, K can be calculated by the equation:

$$\rho_a = K\,R$$

$$\rho_a = K\frac{\Delta V_{P1P2}}{I_{C1C2}} \quad (1)$$

$$K = \frac{2\pi}{\frac{1}{r_{C1P1}}-\frac{1}{r_{C1P2}}-\frac{1}{r_{C2P1}}+\frac{1}{r_{C2P2}}} \quad (2)$$

The data measurement process was carried out using a SuperStingR8/IP resistivitymeter. The length of the track at each point is 600 m. While the data processing is carried out using Ipi2win software so that an overview of the subsurface resistivity value is obtained concerning depth. Depth can be obtained at approximately 25% of the length of the measurement point path (Loke, 2015).

Table 1. Resistivities of various rocks, sediments, and minerals (Telford et al., 1990).

Rock Type	Resistivity Range (Ωm)
Clays	1-100
Unconsolidated wet clay	20
Sandstones	1-6.4 x 10^8
Limestone	50-10^7
Surface waters (sediments)	10-100
Surface waters (igneous rocks)	0.1-3 x 10^3
Natural waters (sediments)	1-100
Natural waters (igneous rocks)	0.-150
Sea water	0.2

4. Results and Discussion

The subsurface lithology at the five measurement points was interpreted based on the correlation between geological data, borehole data, and outcrop observations around the study area with the resistivity values obtained from the measurements. It is known that each type of rock has a specific range of resistivity values. The results of the subsurface lithology interpretation are presented in Table 2. The subsurface resistivity description obtained at each measurement point is NA1 (figure 2), NA2 (figure 3), NA3 (figure 4), NA4 (figure 5), and NA5 (figure 6). The depth obtained in this study was ± 150 m.
Based on the subsurface resistivity values, the points NA1, NA2, NA3, and NA4 are water-saturated layers, except for NA5. The presence of groundwater at these points has been seen starting from a depth of 1.5 m which is indicated by its low resistivity value (<13.5 Ωm).

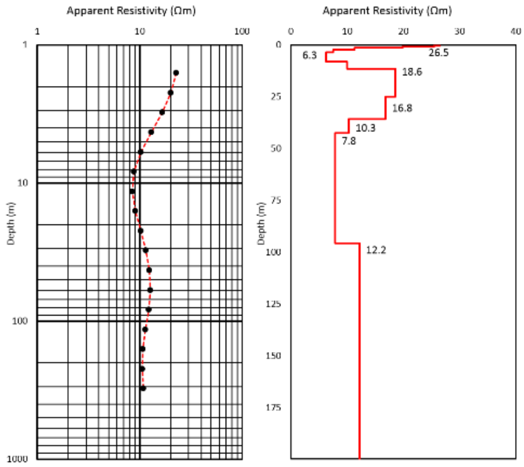

Figure 2. Apparent resistivity curve (NA1)

NA1 is a measurement point located in the Alluvium formation and is flanked by the Idi formation. The NA1 point can be divided into six layers (Table 2). At this point, the potential groundwater layer is identified at a depth of 35.9–95.9 m in the sand layer with resistivity values of 7.8–10.3 Ωm. This result is supported by groundwater depth data from a nearby borehole (05°13'56.08"N, 96°56'10.85"E) located near this point. The groundwater depth in the borehole is recorded at 80 m. During drilling, remains of tree trunks were also found buried at a depth of approximately ±6 m.

This finding indicates that the layer containing the tree trunks was once part of the surface that has since been covered by sediment layers. As a result, the groundwater in this area, up to that depth, is brackish (Idris et al., 2023), which is further supported by the lowest resistivity values (6.3–10 Ωm) found at this point, at a depth of 3.8–11.5 m.

A deeper aquifer was found in a mixed layer of sand and gravels at a depth of >95.9 m with a resistivity of 12.2 Ωm. On the other hand, for the first layer at the NA1 point, located in the Alluvium formation, the resistivity values obtained (19.8–26.5 Ωm) are relatively high, indicating a dense subsurface structure.

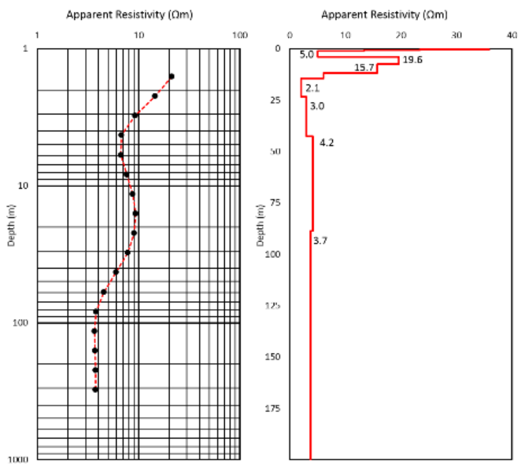

Figure 3. Apparent resistivity curve (NA2)

Point NA2 is located in a lowland area and geologically belongs to the Idi Formation, which borders the Alluvial Formation, similar to point NA3. Therefore, the resistivity cross-section obtained from both points can be considered almost identical. At point NA2, the subsurface layers are divided into seven layers, with the potential groundwater-bearing layers located between depths of 23.6 m to 150

m. The shallow aquifer at this point is identified at depths of 23.6 – 42.8 m, consisting of layers of sand and gravel (3 Ωm). An aquifer is also identified at depths of 42.8 – 88.9 m in layers of sand and calcareous sandstones (4.2 Ωm), while a deeper aquifer is located at depths of 88.9 – 150 m, consisting of sandstone layers (4.2 Ωm). The deeper aquifer, consisting of sandstone, is more favorable compared to the aquifer in the calcareous sandstones, as sandstone has higher porosity. This is also supported by the discovery of a nearby borehole located approximately ±130 m to the south of point NA2, with the borehole depth reaching 120 m.

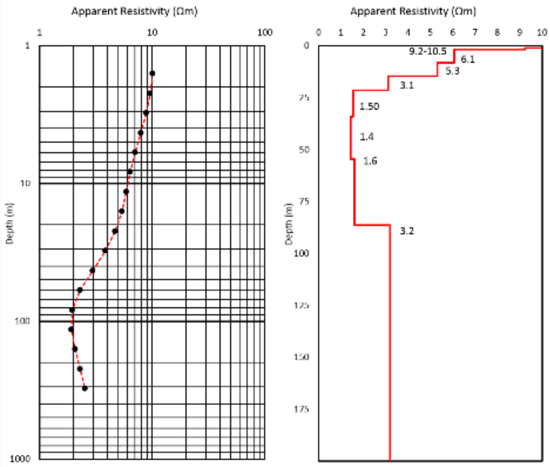

Figure 4. Apparent resistivity curve (NA3)

NA3 is located in a lowland area. Based on the resistivity cross-section, this point consists of six layers, with the subsurface layer having the most conductive resistivity values compared to other points. The aquifer at this location is identified at depths of 21.7 – 150 m. However, the most potential aquifer layer is found at depths of 54.5 – 86.5 m, consisting of sand mixed with calcareous sandstones (1.6 Ωm). The lower resistivity values (1.4 – 1.5 Ωm) at depths of 21.7 – 54.5 m indicate a rock layer containing brackish water. The upper layer of NA3 is also part of the Alluvium Formation, similar to that found at NA2.

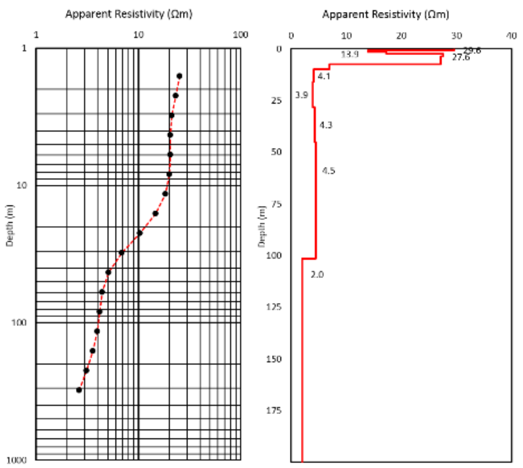

Figure 5. Apparent resistivity curve and lithological interpretation (NA4)

NA4 is located in a lowland area, similar to several other points. However, the resistivity cross-section at this point shows higher values compared to other points. The subsurface layers at this point can be divided into seven layers. The aquifer depth is identified to range from 7.6 to 101 m. An aquifer with good groundwater potential is found at a depth of 28.5–101 m, consisting of calcareous sandstones and sandstones (4.3–4.5 Ωm). Nevertheless, community boreholes are generally drilled at shallower depths, as seen in a borehole (05°14’12.06”N, 96°59’59.94”E) located approximately 90 m northwest of point NA4, with a depth of ±20 m.

Unlike other points, the layer at a depth of 101–150 m (seventh layer), with a resistivity value of 2 Ωm, is identified as mudstones. Meanwhile, the layer above, at a depth of 45.3–101 m with a resistivity value of 4.5 Ωm, is identified as sandstones. Although sandstone can hold water, its resistivity is generally higher than that of mudstone due to its higher permeability and the dominance of quartz components, which are less conductive (Kirsch, 2006).

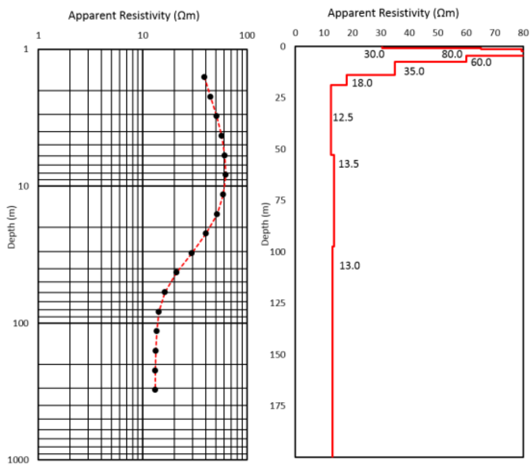

Figure 6. Apparent resistivity curve (NA5)

Point NA5 is located above the hills with a very complex geology. The resistivity value obtained at this point is the most resistive, namely 12.5 – 88.0 Ωm. The rock layers exposed in the field (NA5) very clearly show that the upper layer is clastical limestone and the layer below is reef limestone.

The thickness of the clastical and reefal limestones seen around this measurement point varies greatly and is spread unevenly. Sometimes the rocks are covered by layers of clays of varying thickness. The Tufffaceous sandstones are also seen as the top layer in the northern part which has a lower topography. Based on the subsurface resistivity value, the presence of groundwater at point NA5 has been identified starting from a depth of 18.8 m in a layer consisting of clays (dominant) and sandstones (12.5 Ωm). However, for layers that have more potential to contain groundwater, they are from a depth of 52.8 – 97.5 m in the sands and calcareous sandstone layers (13.5 Ωm) and depths > 97.5 in the sandstones and clays layers. The groundwater in drilled wells around the location was found at a depth of 70 m with clear but slightly calcareous water conditions.

As for silty clays which are said to be aquitards, in a wide distribution area they can also be used as a potential layer for groundwater exploration.

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Table 2. Interpretation of subsurface lithology based on correlation of geological data outcrops around the site, and drilled well data with resistivity values measured.

No.	VES Point	Coordinate Latitude	Coordinate Longitude	Altitude (m)	Layers (n)	Resistivity (Ωm)	Depth (m)	Lithology Interpretation
1.	NA1	05°13’55.42” N	96°56’9.21”E	7	1	19.8 – 26.5	1.5	Gravels
					2	7.5 – 11.3	1.5 – 3.8	Silty clay (aquitard)
					3	6.3-10	3.8 – 11.5	Sandy silty clay
					4	16.8-18.6	11.5 – 35.9	Gravels, sand
					5	7.8 – 10.3	35.9 – 95.9	Sand (aquifer)
					6	12.2	95.9 - 150	Sand, gravels (aquifer)
2.	NA2	05°14’4.74”N	96°57’11.94” E	5	1	13.4 - 35.9	1.3	Gravels
					2	5.0	1.3 – 4	Silty clay (aquitard)
					3	15.7 -19.6	4 – 12.0	Clays, gravels
					4	2.1- 6.0	12.0– 23.6	Sandy silty clay
					5	3.0	23.6 – 42.8	Sand, gravels (aquifer)
					6	4.2	42.8 – 88.9	Sand, calcareous sandstones (aquifer)
					7	3.7	88.9-150	Sandstones (aquifer)
3.	NA3	05°14’20.98” N	96°58’45.70” E	5	1	9.2 – 10.5	1.9	Gravels and clays
					2	6.1	1.9 – 8.3	Clays
					3	5.3	8.3 – 14.7	Silty clay (aquitard)
						3.1	14.7 –21.7	Sandy silty clay
					4	1.4-1.5	21.7 – 54.5	Sand, Calcareous mudstones
					5	1.6	54.5 - 86.5	Sand, calcareous sandstones (aquifer)
					6	3.2	86.5-150	Sandstones (aquifer)
4.	NA4	05°14’09.09” N	96°59’58.76” E	6	1	29.6	1	Gravels
					2	13.9 – 17.9	1-2.5	Clays, gravels
					3	7.0 - 27.6	2.5 - 7.6	Clays,
					4	3.9 - 4.1	7.6 – 28.5	Sand (aquifer), Silty clays
					5	4.3	28.5 – 45.3	Calcareous sandstones (aquifer)
					6	4.5	45.3 - 101	Sandstones (aquifer)
					7	2	101 - 150	Mudstones
5.	NA5	05°13’56.44” N	96°59’0.95”E	37	1	30.4 –	0.8	Clastical limestone, clays
					2	65.2 – 88.0	0.8 - 4.6	Reefal limestones, clays
					3	35.0 – 60.0	4.6 – 14.0	Gravels, clays
					4	18	14.0 – 18.8	Clays, gravels
					5	12.5	18.8 – 52.8	Clays, sandstones
					6	13.5	52.8 – 97.5	Sand, Calcareous sandstones (aquifer)
					7	13	97.5-150	Sandstones (aquifer)

5. Conclusions

Based on the analysis results, it was found that the aquifer layer (<13.5 Ωm) in the study area consists of sand, a mixture of sand and gravel, calcareous sandstone, and sandstone. The depth of the aquifer layer with the best potential at each location point is at 35.9–150 m (NA1), 23.6–150 m (NA2), 54.5–150 m (NA3), 28.5–101 m (NA4), and 52.8–150 m (NA5). Points NA1, NA2, NA3, and NA4 indicate the presence of water-saturated layers that begin at shallow depths (1.5 m). In contrast, point NA5, located in a hilly area with complex geology, has more resistive layers and more limited groundwater potential compared to the other points.

Acknowledgments:

Thanks to AKSI-ADB Malikussaleh University for funding this research with AKSI ADB funding sources in 2023. Thank you also to all friends who have assisted in the data acquisition process in the field, and all parties who have provided other supporting data.

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