Indonesian Physical Review

Volume 08 Issue 01, January 2025

P-ISSN: 2615-1278, E-ISSN: 2614-7904

Identification of Aquifers based on the Vertical Electrical Sounding (VES) Method Schlumberger Configuration Case Study: Pulau Baai Kampung Melayu Sub-district, Bengkulu City, Indonesia

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Article Info

Article info:
Received: 25-04-2024
Revised: 05-09-2024
Accepted: 11-09-2024

Keywords:
Aquifers; VES; Schlumberger Configuration; Kampung Melayu

How To Cite:
T. Al Rafly, Refrizon, A. I. Hadi, A. R. Al Ansory, and H. Raihana, "Identification of Aquifers based on the Vertical Electrical Sounding (VES) Method Schlumberger Configuration Case Study: Pulai Baai Kampung Melayu Sub-district, Bengkulu City, Indonesia," Indonesian Physical Review, vol. 8, no. 1, p 1-16, 2025.

DOI:
https://doi.org/10.29303/ipr.v8i1.333.

Abstract

Investigation of the groundwater potential in the Pulau Baai area, Kampung Melayu Sub-district, Bengkulu City, must be carried out in such a way that the activities and needs of the people in the area can be fulfilled and the needs of the population in the area can be met. This study aims to determine the status of groundwater using the Schlumberger configuration geoelectric method. Measurements were made using a resistivity meter, and the results for each configuration depended on changes in resistivity. Measurements for each configuration depend on changes in resistivity at depth, the vertical direction (sounding), and the lateral direction (mapping), so hydrogeological analysis in this activity aims to get the maximum use of groundwater / underground water in aquifers for raw water needs. The dominant rock structures in the study area are clay, alluvium, siltstone, and sandstone, as well as some rocks with suitable porosity and permeability as water carriers, such as sand and gravel. However, what appears to have considerable potential is that groundwater is found at depths of 4-53 meters in VES 1, VES 2, VES 3, VES 5, and VES 10. The results of the analysis show that the location of the Pulau Baai, Kampung Melayu Sub-district, Bengkulu City Priority Utilization Area is within the groundwater storage area, so it can be used to meet the raw water needs of the study area.

Introduction

The formation of groundwater follows the cycle of water circulation on Earth called the hydrological cycle, which is a natural process that takes place in water in nature and undergoes a sequential and continuous movement [1]. Layers that are easily penetrated by groundwater are called permeable layers, such as those found in sand or gravel. In contrast, layers that are difficult for groundwater to penetrate are called impermeable layers, such as clay layers [2]. Pore spaces and fissures in rock grains will be filled by surface water that has entered the ground through infiltration. In addition to being described vertically, geological formations that act as aquifers (water-bearing strata) can be used to determine the horizontal distribution of groundwater [3].

Groundwater stored in an aquifer is a geological rock formation that is saturated with water and capable of passing water in sufficient quantities [4]. This aquifer layer tends to have high rock porosity and stores and drains groundwater [5]. Rock porosity is the ratio of the volume of the cavities to the volume of the entire rock, expressed as a percentage [6]. Water/fluid will be trapped in a rock with a high porosity [7]. Therefore, this research will be conducted to find the aquifer layer using the ESR method. The VES method is used to characterize changes in physical parameters in the form of resistivity values in the subsurface [8].

Previous research on groundwater has also been conducted by [9] based on the results of groundwater using the VES geoelectric method in Kampung Melayu, Bengkulu City, the distribution of groundwater layers in this area varies between 5 to 30 meters in the west and 10 to 50 meters in the east, with resistivity values ranging from 5 Ω.m to 45 Ω.m. However, this research is only spread at various points in the Kampung Melayu area. Still, no specific area is addressed, so this research needs to be done to better know the location of groundwater in an area affected by difficulties in obtaining water for the daily needs of the community around the Pulau Baai area, Kampung Melayu Sub-district, Bengkulu City. `This research aims to determine the distribution of groundwater levels that can be used by the community around the research area.

Groundwater research enormously influences the surrounding community's use of groundwater as a source of clean water [10]. The resistivity method employs one of the electrical properties of a medium subjected to flow [11]. In this instance, the current is conducted into the ground via two electrodes constructed from iron, which serves as the conducting medium. Once the current has been applied to the soil, a potential difference will be generated, which can be quantified using two potential electrodes. The resistivity value of the soil below the surface can be obtained by analyzing the data of the current flowing into the ground and the value of the potential difference that arises between the two points. The resistivity value allows for the estimation of the type of subsurface layer and the possible presence of groundwater (aquifer) [12]. A sufficiently good geophysical method to map subsurface conditions and discover the depth of groundwater is the geoelectrical Vertical Electrical Sounding (VES) method [13]. The Vertical Electrical Sounding (VES) method is a geoelectrical measurement technique that aims to estimate changes in resistivity as a function of depth at the measuring point [14]. Different electrode distances are used in the survey technique, as the distance between the electrodes determines the depth of the survey. The most commonly used electrode configuration is the Schlumberger electrode configuration. Vertical Electrical Sounding (VES) can be used as a probing method for groundwater, tectonics, petrology, metal ore exploration, and geotechnics. This method aims to study the resistivity value of rocks below the earth's surface, thus producing a one-dimensional profile of the resistivity pattern below the earth's surface [15]. This research is expected to model one dimension based on groundwater depth information using Progress 3.0 software, which aims to produce a one-dimensional model. Progress software is used because it is freely accessible. The model results obtained from inversion calculations are 1D resistivity cross sections, depending on the measurement method used. However, it is sometimes desirable to develop the cross-section results in 3D form for deeper interpretation, such as in the work of [16]. Therefore, a numerical method is required to create the 1D resistivity data into 3D, one of which is the interpolation method, is the interpolation method. Interpolation is a technique to obtain a function that passes through all points of a discrete data set, or in other words, an estimation technique or estimation of a point or value between discrete points or a known data set [16]. The focus on shallow groundwater distribution to provide information to the surrounding community and government as a source of clean water supply for various purposes in groundwater recharge areas shows an increasing trend. At the same time, land use in groundwater recharge areas also changes along with development progress. Therefore, further research is needed to verify the groundwater depth and obtain information on rock types in Pulau Baai, Kampung Melayu Sub-district, Bengkulu City, Bengkulu Province.

Regional Geology

In general, the central part of the Geological Map of the Bengkulu Sheet and Surrounding Area [17] at a scale of 1: 250.000, is occupied by several young volcanoes, including Bukit Dingin with an elevation of 2.020 m a.s.l, Bukit Balai (1,683 m a.s.l.), Bukit Condong (2.079 m a.s.l.), Bukit Daun (2.467 m a.s.l.) 020 m a.s.l, Bukit Balai (1.683 m a.s.l.), Gunung Hulupalik (2.493 m a.s.l.) and Bukit Hululais (2.130 m a.s.l.). These mountains form a strato-volcanic chain part of the Bukit Barisan Mountain range, with a common northwest-southeast direction. To the west and east, it is bordered by undulating hills, locally with sharp ridges to the north and south. In the coastal area to the southwest are narrow plains [17].

With a common northwest-southeast direction, the Sumatra Fault cuts through rocks of the Oligocene to Quaternary age. In some places, the Sumatra Fault appears to be the contact between Quaternary volcanic rocks and older solid rocks. According to [18], the narrow plains found locally in the Southwest are formed by loose materials ranging in size from clay to gravel, with a thickness of less than 5 m.

The characteristics of the seismogram change according to the type of geology. Bengkulu City has six types of geological formations, including alluvium (Qa), cliff limestone (Ql), swamp sediment (Qs), Undak alluvium (Qat), andesite (Tpan), and bintunan formation (QTb). Administratively, the population of Bengkulu (civil population and regional offices) is mainly located on the alluvium and the Undak alluvium. The study area has a Qat (Undak Alluvium) sand, silt, clay, and gravel rock formation [19]. This unit is the youngest superficial deposit of the Quaternary Holocene age, composed of sand, silt, clay, and gravel formed from fluvial, beach, and marsh deposits. These deposits are distributed almost throughout Bengkulu from north to south but do not reach the city boundary to the east, with an area of approximately 62.8 percent [20].

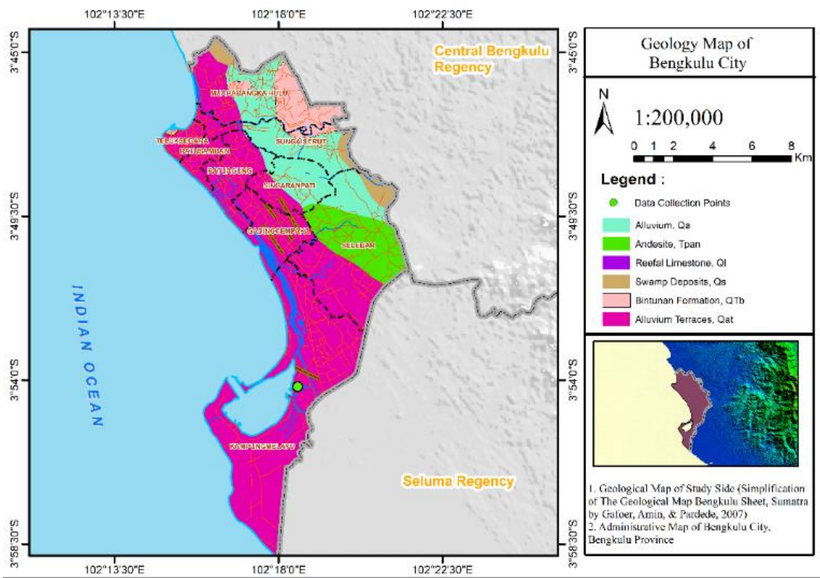

Figure 1. Regional geological map of the city of Bengkulu [17]

Theory and Calculation

Geoelectricity is a geophysical method that studies the nature of the earth's electric currents and how they are measured at the surface [8]. This is achieved by injecting an electric current into the ground. Geoelectricity is one of the active geophysical methods, as the electric current originates from outside the system. The principal objective of this geoelectric service method is to ascertain the resistivity or specific resistance of rocks. Resistivity or specific resistance is a quantity or parameter demonstrating the electrical resistance level to electric current. The greater the resistivity of a rock, the more difficult it is to electrify. In addition to rock resistivity, geoelectric methods can also be employed to ascertain other electrical properties, including electric potential and induced field [5]. These measurements include naturally occurring potentials and winds due to current injection into the ground. The term Sounding is derived from Vertical Electrical Sounding (VES). This geoelectrical measurement technique aims to estimate the change in resistivity as a function of depth at a measuring point [8]. Since the distance between electrodes determines the depth of the survey, the sounding technique is performed with varying distances between electrodes. The borehole is a measurement of the subsurface and the distribution of geoelectric points vertically up to a considerable depth. The assumption is that there is no lateral effect in the direction of the electrode section. The electrode configuration often used in sounding measurements is the Schlumberger configuration [13]. The Schlumberger configuration uses four electrodes with two potential electrodes and two current electrodes arranged in a straight line, making the possible electrode distance more minor than the current electrode distance. The measured value is apparent resistivity (ρa). The working principle of this method using the formula [13]. In Schlumberger electrode configuration, M and N are used as potential electrodes and A and B as current electrodes. The distance between the current electrodes is much larger than between the Schlumberger configuration's potential electrodes. The diagram of this electrode rule can be seen in Figure 2, so it is known that the distance between the current electrodes is

2L, while the distance between the potential electrodes is 2L. The rule to be observed is that (L) is much larger than l [21].

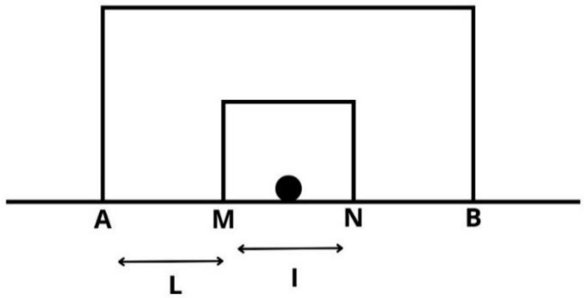

Figure 2. Electrode spacing rules in the Schlumberger configuration [8]

Experimental Method

This research aims to verify the groundwater depth on Pulau Baai in the Kampung Melayu Sub-district of Bengkulu City, which is suspected to be a potential liquefaction area. The results of this study will show the depth of groundwater and the characteristics of the rocks that make up the potential liquefaction area, which has shallow groundwater and a passive rock structure, so this area is very vulnerable to potential liquefaction. Field data acquisition was carried out on 20 June 2023, with as many as 12 survey points scattered across the Kampung Melayu Sub-district, with a trace length at each survey point of 200 meters. The measurement trajectory took the form of a line or a straight line, adjusting for the conditions of the measurement area. An illustration of measurements in the field can be seen in Figure 3. The results of the field measurements were processed in the form of 1D models using Excel and Progress software.

The working principle of the Schlumberger configuration in resistivity geoelectric logging [22] is illustrated in Figure 4. From the figure, the MN electrode spacing is made small so that, theoretically, there is no change in the MN electrode spacing. While the current electrode AB is moved up to the specified stretch length. The distance between electrodes A and M or B and N is a multiple of the stretch length MN. The stretch arrangement between the potential electrode MN and the current electrode AB must satisfy the condition that the distance MN/2 is 1/5 of the distance AB/2. [23].

$$K = \pi \frac{(L^2 - l^2)}{2l} \quad (1)$$

$$\rho_a = K \frac{V}{I} \quad (2)$$

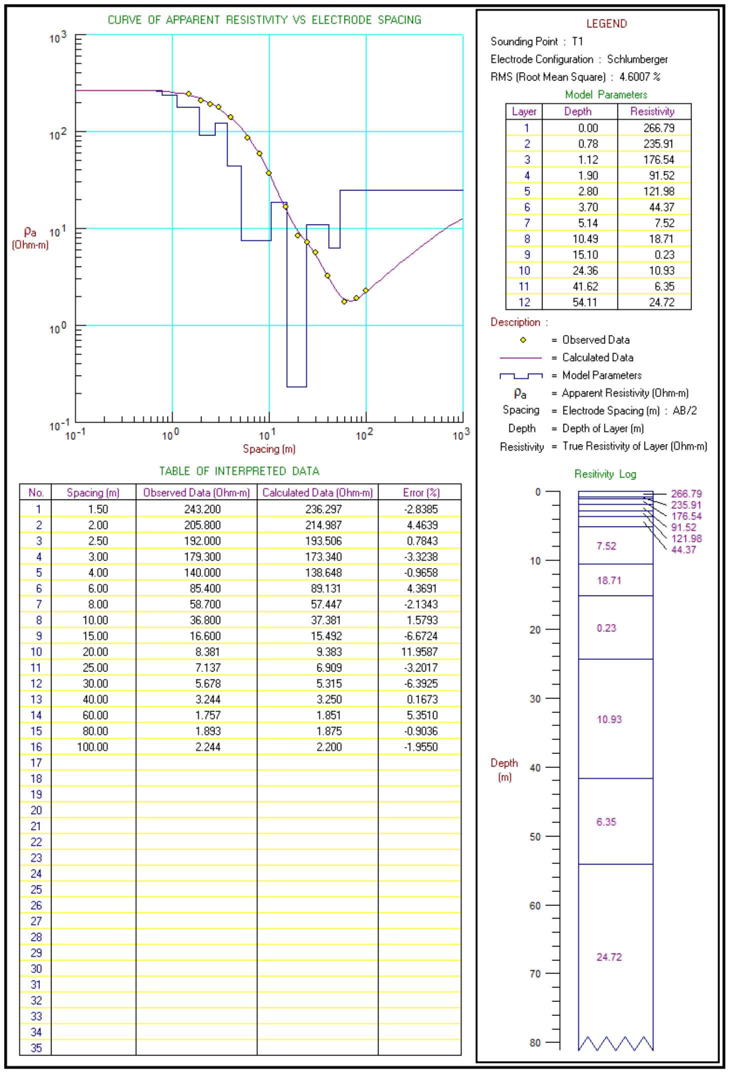

Figure 3. Data processing results of 1st Dimension VES-1 point with progress software

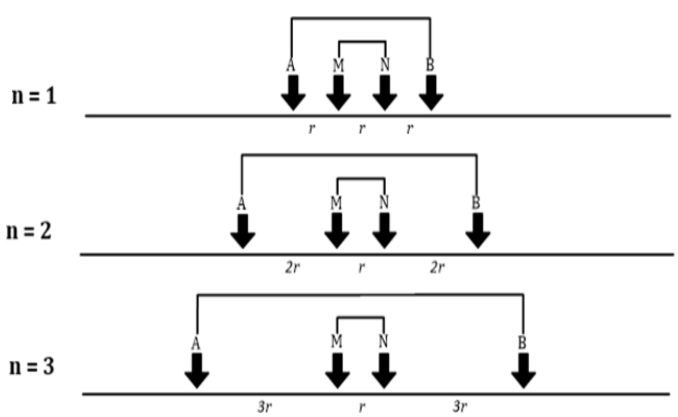

Figure 4. Illustration of field measurements [23]

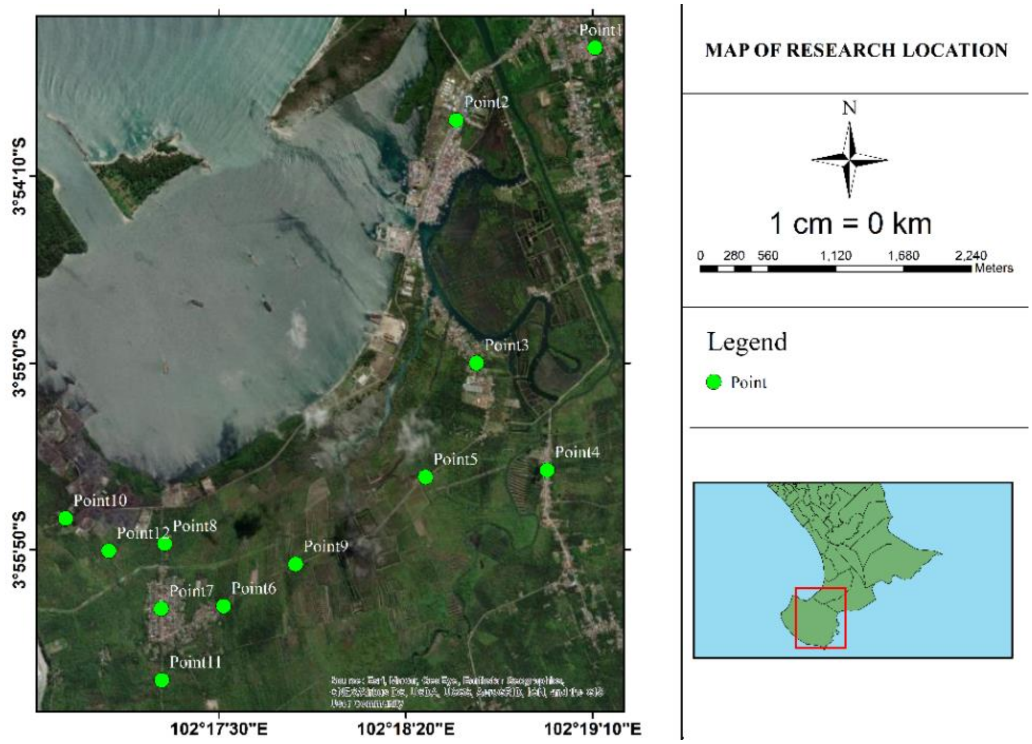

Figure 5. Map of the research area

Result and Discussion

The interpretation of the 1D geoelectrical data (Table 1) is based on the Telford resistivity value table [24] and is adapted to the geological conditions of the data collection site. The results from each point show different depths, thicknesses, and rock resistivity values in each layer. The results of the 1-dimensional data were then modeled in 3 dimensions to see the distribution of the water table in the research area. The data processing is generated by the least squares inversion process based on the electrical properties of rocks below the earth's surface. Groundwater cannot be observed directly through the earth's surface; the investigation of the ground surface is an essential preliminary investigation, at least it can provide an idea of the location of groundwater [25]. The determination of groundwater potential always refers to quantity, which refers to the availability of groundwater and its quality [26]. Data processing using progress software made three-dimensional modeling to see the distribution of the groundwater table. The results of this 1-dimensional data are in the form of resistivity and depth values [27].

The results of this 1-dimensional processing will later be calculated into a 3-dimensional model to more significantly see the potential of the groundwater table in the research area. The results of this 1D modeling are interpolated into a 3D model [28]. Interpolation is a technique for obtaining a function that passes through all the points of a discrete data set, or in other words, estimating a point or value between discrete points or a known data set. This interpolation method searches for the mid-point. This research is expected to benefit the surrounding community by providing groundwater suitable for consumption, as it is known that this research area is a coastal area where the water used is primarily salty. Through this research, it is hoped that it can become a benchmark for the surrounding community in making wells to get groundwater that can be used for the community's daily needs.

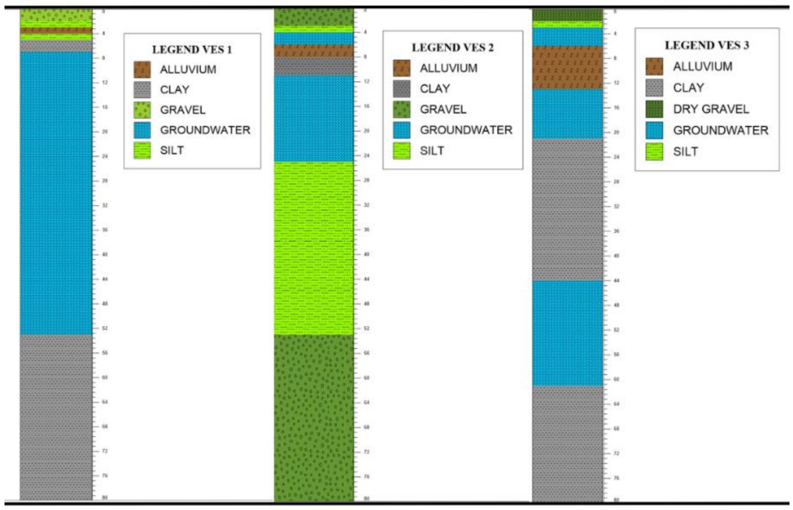

Figure 6. a) Lithology of VES 1, b) Lithology of VES 2, c) Lithology of VES 3

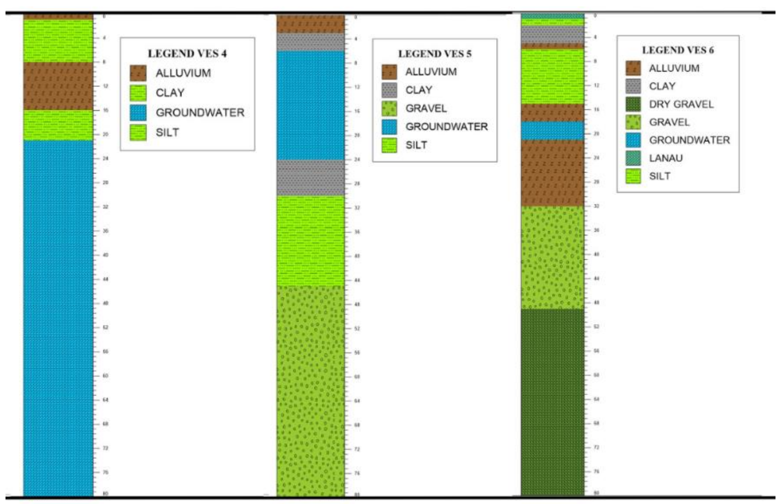

Figure 7. a) Lithology of VES 4, b) Lithology of VES 5, c) Lithology of VES 6

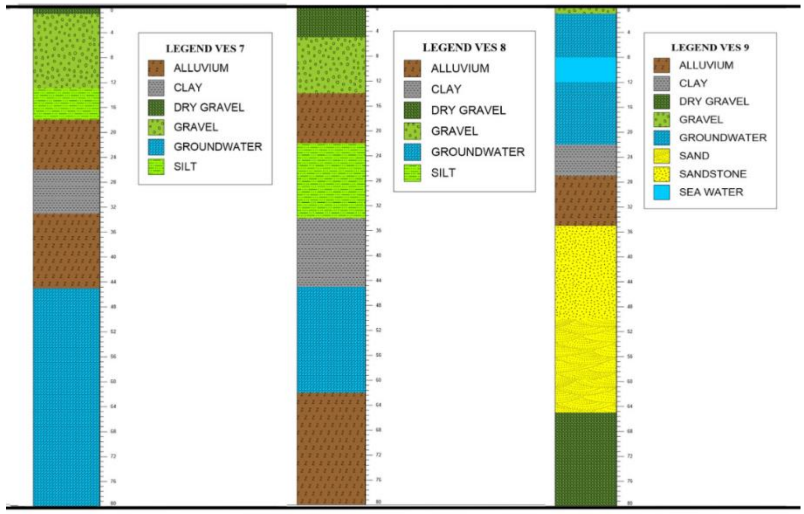

Figure 8. a) Lithology of VES 7, b) Lithology of VES 8, c) Lithology of VES 9

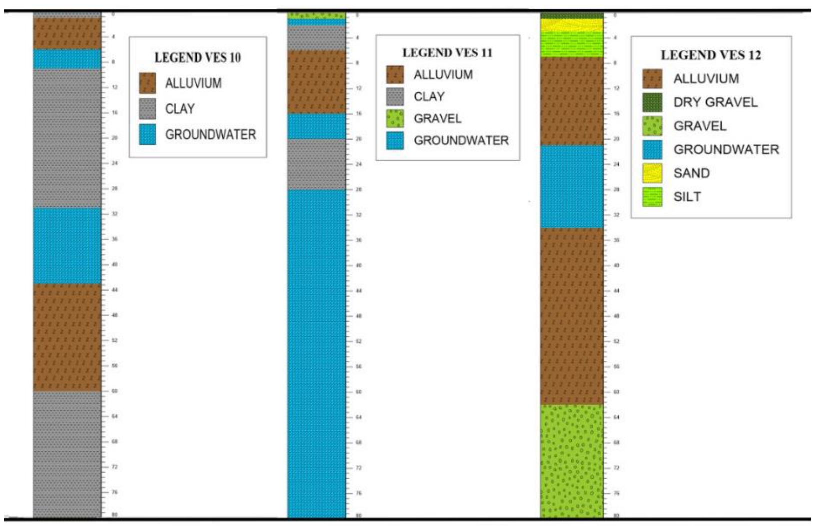

Figure 9. a) Lithology of VES 10, b) Lithology of VES 11, c) Lithology of VES 12

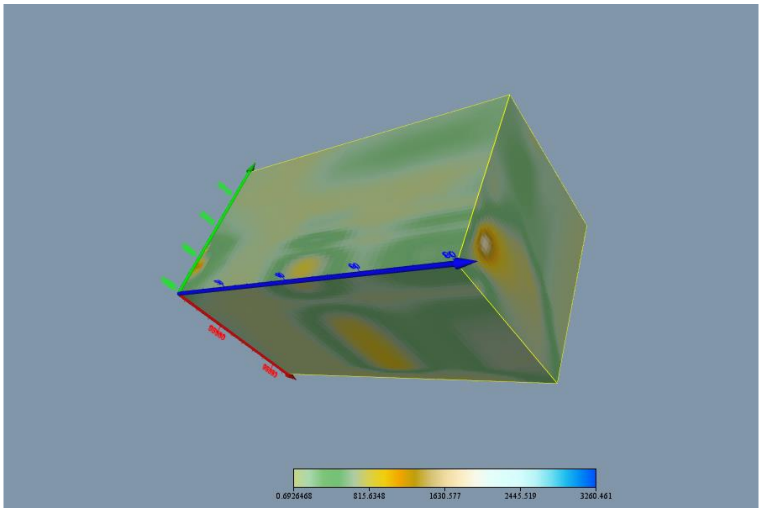

Figure 10. Three-dimensional modeling of the water table

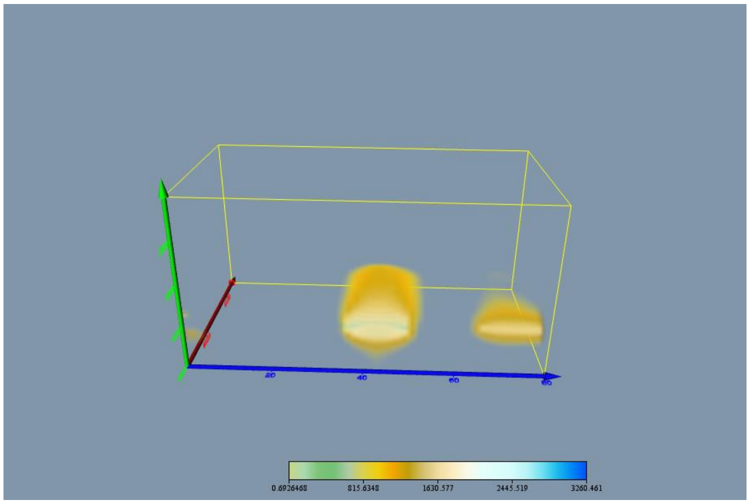

Figure 11. Volumetric modeling of the three-dimensional water table

Table 1. Interpretation at each research point location

No	Site	Depth (m)	Thickness (m)	Resistivity (Ωm)	Lithology
1	VES 1	0-1	1	266.79	Gravel
		2	1	236.91	Gravel
		3	1	176.54	Silt
		4	1	91.62	Alluvium
		5	1	121.98	Silt
		6-7	2	44.37	Clay
		8-11	4	7.52	Groundwater
		12-14	3	18.71	Groundwater
		15-24	10	0.23	Groundwater
		25-42	18	10.93	Groundwater
		43-53	11	6.35	Groundwater
		54-80	27	24.72	Clay

Table 1. Interpretation at each research point location

No	Site	Depth (m)	Thickness (m)	Resistivity (Ωm)	Lithology
2	VES 2	0-1	1	278.22	Gravel
		2	1	194.15	Gravel
		3	1	186.78	Gravel
		4	1	111.26	Silt
		5-6	2	18.62	Groundwater
		7-8	2	44.32	Alluvium
		9-11	3	23.44	Clay
		12-18	7	2.1	Groundwater
		19-25	7	5.31	Groundwater
		26-38	13	107.01	Silt
		39-53	15	109.56	Silt
		54-80	27	274.2	Gravel
3	VES 3	0-1	1	698.73	Dry Gravel
		2	1	902.53	Dry Gravel
		3	1	133.57	Silt
		4-6	3	16.68	Groundwater
		7-9	3	91.91	Alluvium
		10-13	4	41.11	Alluvium
		14-21	8	6.67	Groundwater
		22-44	23	21.6	Clay
		45-55	11	16.7	Groundwater
		56-61	6	19.16	Groundwater
		62-80	19	25.97	Clay
4	VES 4	0-1	1	55.59	Alluvium
		2	1	22.24	Clay
		3-4	2	160.33	Silt
		5-8	4	165.29	Silt
		9-12	4	98.95	Alluvium
		13-16	4	59.43	Alluvium
		17-21	5	21.06	Clay
		22-31	10	0.92	Groundwater
		32-50	19	3.37	Groundwater
		51-80	30	0.89	Groundwater
5	VES 5	0-1	1	72.28	Alluvium
		2	1	73.82	Alluvium
		3	1	49.79	Alluvium
		4-6	3	28.76	Clay
		7-10	4	10.57	Groundwater
		11-14	4	11.9	Groundwater
		15-19	5	4.37	Groundwater
		20-24	5	14.8	Groundwater
		25-29	5	30.31	Clay
		30	1	37.49	Clay
		31-45	15	164.1	Silt
		46-80	35	202.24	Gravel
6	VES 6	0-1	1	134.55	Lanau
		2	1	164.52	Silt
		3-5	3	32.74	Clay
		6	1	57.76	Alluvium

Table 1. Interpretation at each research point location

No	Site	Depth (m)	Thickness (m)	Resistivity (Ωm)	Lithology
		7-10	4	100.28	Silt
		11-15	6	103.61	Silt
		16-18	3	50.51	Alluvium
		19-21	3	1.13	Groundwater
		22-32	11	58.69	Alluvium
		33-49	17	459.82	Gravel
		50-80	30	609.58	Dry Gravel
7	VES 7	0-1	1	1747.09	Dry Gravel
		2	1	278.1	Gravel
		3-4	2	389.47	Gravel
		5-8	4	559.45	Gravel
		9-13	5	432.68	Gravel
		14-18	5	189.95	Silt
		19-26	8	95.81	Alluvium
		27-33	7	29.97	Clay
		34-45	12	45.81	Alluvium
		46-60	15	7.13	Groundwater
		60-80	20	5.99	Groundwater
8	VES 8	0-1	1	1160.09	Dry Gravel
		2	1	2275.44	Dry Gravel
		3-5	3	1185.09	Dry Gravel
		6-9	4	290.09	Gravel
		10-14	5	311.45	Gravel
		15-22	8	80.23	Alluvium
		23-34	12	105.53	Silt
		35-45	11	58.13	Clay
		46-62	17	28.39	Groundwater
		63-80	18	73.56	Alluvium
9	VES 9	0-1	1	229.88	Gravel
		2	1	9.9	Groundwater
		3-8	6	9.64	Groundwater
		9-12	4	0.04	Sea water
		13-16	4	2.46	Groundwater
		17-22	6	17.78	Groundwater
		23-27	5	22.23	Clay
		28-35	8	64.38	Alluvium
		36-50	15	3487.61	Sandstone
		51-65	15	636.9	sand
		66-80	15	2048.1	Dry Gravel

Table 1. Interpretation at each research point location

No	Site	Depth (m)	Thickness (m)	Resistivity (Ωm)	Lithology
10	VES 10	0-1	1	38.51	Clay
		2-3	2	59.14	Alluvium
		4-6	3	46.44	Alluvium
		7-9	3	7.48	Groundwater
		10-14	5	29.17	Clay
		15-19	5	29.73	Clay
		20-25	6	33.31	Clay
		26-31	6	22.64	Clay
		32-43	12	11.26	Groundwater
		44-60	17	63.52	Alluvium
		61-80	20	33.36	Clay
11	VES 11	0-1	1	390.6	Gravel
		2	1	18.48	Groundwater
		3-6	4	40.46	Clay
		7-10	4	55.87	Alluvium
		11-16	7	52.29	Alluvium
		17-20	4	3.02	Groundwater
		21-28	8	32.89	Clay
		29-41	13	18.95	Groundwater
		42-59	18	12.47	Groundwater
		60-80	20	13.57	Groundwater
12	VES 12	0-1	1	956.09	Dry Gravel
		2	1	619.35	Sand
		3	1	778.62	Sand
		4-7	4	190.75	Silt
		8	1	85	Alluvium
		9-13	5	94.82	Alluvium
		14-21	8	50.78	Alluvium
		22-34	13	25.53	Groundwater
		35-40	6	86.33	Alluvium
		41-62	22	67.89	Alluvium
		63-80	18	267.24	Gravel

This study was conducted in a coastal area where groundwater is difficult to locate. The study area is considered to have poor surface water quality. This is influenced by the area's proximity to the coast, which is dominated by salt water, making it difficult to reach groundwater that can be used by the community. According to information obtained from the community, the depth of groundwater when drilling wells is 50 meters from the surface. This condition requires research into the subsurface structure and the characteristics of the constituent rocks [21]. The results of this study should provide information, solutions, and recommendations for coastal communities when searching for groundwater. With the data interpretation results at VES 7, VES 8, and VES 12, it can be stated that the unconfined aquifer layer is a sandstone layer beneath the impermeable clay layer. This unconfined phreatic aquifer is the area of most excellent rainwater catchment. It can, therefore, be assumed that the groundwater stores water during the rainy season, but the existence of the aquifer is at such a depth that, when water is to be obtained, the following steps must be taken drilling to a considerable depth since the upper layer is impermeable.

The results of the measurements in each VES of the coastal zone present alluvial rock types, one of which can be seen in Table 1, interpreted by [24]. The dominant rock structures in this research area are clay, alluvium, siltstone, and sandstone, as well as some rocks with good porosity and permeability as water carriers, such as sand and gravel. After investigating the research site, the dominant groundwater was found at a 15-80 meters depth. In the results of each lithological model in VES 1, VES 2, VES 3, VES 5, and VES 10, the groundwater is found at a depth of 4-53 meters and is dominated by gravel, silt, clay, and alluvium. The VES 1 area has abundant groundwater. Therefore, abundant and good-quality groundwater is recommended. From the data interpretation results in VES 7, VES 8, and VES 12, it can be stated that the unconfined aquifer layer consists of a sandstone layer beneath the impermeable clay layer. This unconfined phreatic aquifer is the area of the most excellent rainwater catchment. It can, therefore, be assumed that groundwater stores water during the rainy season, but the water table is at a considerable depth, so when you want to obtain water, you must drill to a significant depth. This is because the upper layer is impermeable. Aquifers are present in almost the entire measurement area. With varying thicknesses, bear in mind that these aquifers are not all full of water; only the pores of the rock are full of water, and they are not necessarily full of water.

Conclusion

The results of the potential groundwater level in Pulau Baai, Kampung Melayu Sub-district, Bengkulu City, using the Vertical Electrical Sounding (VES) geoelectric method show that the research area has a potential groundwater level in the coastal area, each measurement point has a fairly even distribution of groundwater level and relatively the same rock type. The dominant rock structures in this study area are clay, alluvium, siltstone, sandstone, and some rocks with good porosity and permeability as water carriers, such as sand and gravel. However, those that appear to have significant potential are in VES 1, VES 2, VES 3, VES 5, and VES 10. The results of the data analysis show that this area is ideal for groundwater storage, and it can be used as a water source for the people of Pulau Baai.

Acknowledgment

We want to thank those who contributed to this research, which was fully supported by the Bengkulu University Geophysics curriculum, especially the supervisors who helped with data processing up to the interpretation stage. We would also like to thank the people of Pulau Baai, Kampung Melayu Sub-district, Bengkulu City, who welcomed us well and kindly during our research.

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