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Investigation of the Geothermal Resource Potential Using Geoelectrical Method with the Wenner Configuration: A Case Study in Lebong Regency, Indonesia

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Abstract

In geothermal reservoirs, hydrothermal distribution is significant. The most widely utilized geothermal reservoirs to date are those of hydrothermal systems, which are geothermal systems where the reservoir contains steam, water, or a mixture of both, depending on the pressure and temperature of the reservoir. One of geophysical method that is enough to map subsurface conditions to determine the hydrothermal distribution is the 2-Dimensional Geoelectric method using the Wenner configuration. This method aims to study the variation of rock resistivity below the earth's surface, resulting in a two-dimensional profile of the subsurface resistivity model used to describe the layered subsurface resistivity structure. The results are in the form of 2-Dimensional modeling of the distribution of hydrothermal manifestations with data processing using pyGIMLI (Python Library for Inversion and Modeling in Geophysics) software. In the study area Pungguk Pedaro Village, Bingin Kuning District, Lebong Regency, the Hulusimpang Formation has a high alteration intensity, as evidenced by the weathering in rocks and the micrographic appearance. The types of stones found in this research area include andesite rocks, including sandy gravel, volcanic breccia, tuff, andesite, basalt, basalt-andesite sand, silty sand, and clay. Or rocks derived from acidic magma.

Introduction

Indonesia is located at the meeting zone of three major plates of the world, namely the Indo-Australian, Eurasian, and Pacific Plates which play a role in the process of volcano formation in Indonesia [1]. The existence of geothermal potential is indicated by manifestations, such as hot springs, fumaroles, and altered rocks, which are caused by tectonic activity that causes faulting and allows fracture zones to exist [2].

One area with potential hot springs is Pungguk Pedaro Village, Bingin Kuning District, Lebong Regency, Bengkulu Province. The presence of secondary permeability in the form of the Ketahun fault influences the existence of this geothermal manifestation. This fault controls the hot fluid in the reservoir to flow to the surface in the form of hot springs, rock alteration, and fumaroles that appear. The rock geology of this area consists of granite, andesite, and basaltic rocks. The hydrothermal area in the Pungguk Pedaro spring is also closely related to the magmatic activity in the Bukit Barisan range [3].

Previous research on Air Putih hot springs has also been conducted by [4] based on geothermal distribution with the geoelectric method of specific resistance in Air Putih village, Pinang Belapis District. The results concluded that it is hydrothermal with a particular value of gravity of 3.71 Ωm at a depth of 78.4 m and interpreted as geothermal seepage. However, research in the Lebong Regency area only focused on Air Putih village, Pinang Berlapis District, despite many hydrothermal manifestations in Lebong Regency. This study aims to determine the direction of hydrothermal distribution in Lebong Regency, which is thought to originate from Bukit Daun.

In geothermal reservoirs, hydrothermal distribution is significant. One geophysical method that is good enough to map subsurface conditions to determine the hydrothermal distribution is the 2-Dimensional Geoelectric method using the Wenner configuration. This method aims to study the variation of rock resistivity in the earth's subsurface. So that it produces a two-dimensional profile of the resistivity model in the subsurface and is used to describe horizontal variations (2 Dimensions) in the layered subsurface resistivity structure, this research is expected to be able to model in 2 Dimensions the distribution of hydrothermal manifestations with data processing using pyGIMLI Software (Python Library for Inversion and Modeling in Geophysics), whose purpose is to produce a 2-Dimensional model [5]. The pyGIMLI software was used because the software can be accessed freely, and the data processing process does not take long. A focus on hydrothermal distribution is also needed if the government wants to conduct drilling for geothermal exploitation. Therefore, further research is required to see the hydrothermal distribution and determine the type of rock in Pungguk Pedaro Village, Bingin Kuning District, Lebong Regency, Bengkulu Province.

Regional Geology

Based on the Regional Physiography of Sumatra Island, according to [6], this area is included in the Zone of the Barisan range, in which, in the core, there are granite rocks that indicate the presence of magma activity in the study area. The granite igneous rocks of the study area are included in the Breakthrough Rock (tmgr), which has tertiary elements. According to [7] in the Geological Map of Bengkulu Sheet. Based on the results of a particular study of Petrogenesa analysis of granite rocks in the Lebong Regency area and its surroundings, it can be concluded that granite rocks are formed at an average temperature of (400 – 800)^{o}C pragmatic-pneumatolytic phase, with acidic magma types with calcite-Alkali magma series. The geological structure in the study area occurred at the time of the late Miocene main force direction or relatively north-south.

The study area is tectonically located in the fore-arc basin of the Bengkulu Basin. Deposition in the Neogene was influenced by the structural evolution of the bay [8]. Then, [9] also argued that the sediments in the Bengkulu Basin are controlled by the activity of dextral strike-slip fault systems called the Mentawai Fault Zone (MFZ) and Sumatra Fault Zone (SFZ). It is assumed that fault activity influences the formation of tertiary sedimentary basins (pre-rift) but can also act as a separator between basins that occurs long after the sedimentation process takes place. Thus it can be concluded that horizontal faults on the island of Sumatra have a deep-seated nature so that they penetrate the bedrock (basement involved). This nature and faulting give rise to magmatism/volcanism activity on the surface. In the Late Oligocene, the Hulusimpang Formation (Tomh) was deposited due to the volcanism phase in the Eocene to Early Oligocene. Then in the Early Miocene, the basin decreased so that the water level rose, and sedimentary material from the Seblat Formation (Toms) to the Middle Miocene was deposited in a series [10].

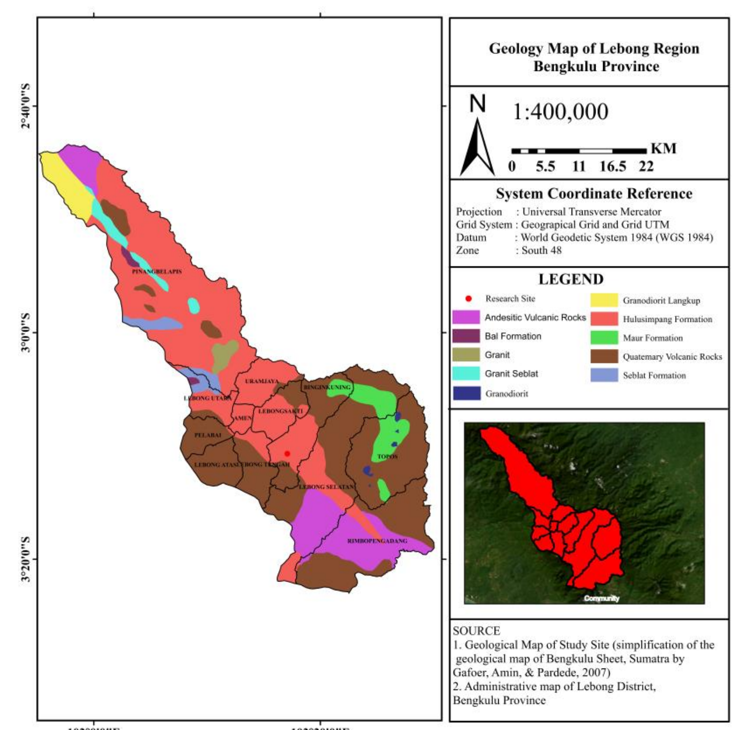

Figure 1. Geology Map of Lebong Region

Theory and Calculation

Geoelectricity is one of the methods in geophysics that studies the nature of electrical flow in the earth [11]. Detection above the surface includes measuring potential, current and electromagnetic fields that occur naturally and due to the injection of current into the earth. In this research, the discussion is devoted to the geoelectric method of specific resistance. In the particular resistance geoelectric method, electric current is injected into the earth through two current electrodes (located outside the configuration). The potential difference is measured through two potential electrodes in the configuration [11].

This resistivity method is generally only suitable for shallow excavations of about 100 meters. If the layer depth is more than this price, the information obtained is less accurate due to the weakening of the electric current for more considerable span distances. Therefore, this method is rarely used for deep exploration. The resistivity method is more widely used in determining the depth of bedrock, searching for water reservoirs, detecting seawater intrusion, and searching for geothermal fields.

From the measurement of electric current and potential difference, the variation of resistivity value in the measured layer can be obtained. An illustration of the equipotential line that occurs due to current injection at two opposite current issues on the earth's surface can be seen in Figure 2. The greater the distance between electrodes, the deeper the soil can be measured.

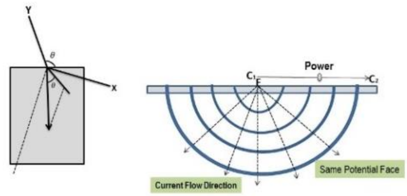

Figure 2. Flow Pattern of an Equipotential Field [12]

The concept of electrical propagation applies to isotropic homogeneous media by measuring the difference in potential value between two measurement points that occurs due to the flow of electric current traveling unidirectionally through the subsurface of the earth. The basis of the typical resistance method is Ohm's law which was first coined by George Simon Ohm. He formulated the relationship between voltage and electric current at pinch voltage. For finite media (cylinder, beam), it applies:

$$R = \frac{\Delta V}{I} \quad (1)$$

with R is the electrical resistance in ohms. ΔV is the potential difference in Volts. And I is the amount of electric current in Amperes.

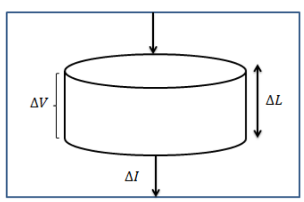

Figure 3. Cylinder model [12]

If reviewed from Figure 3, which is a conductor cylinder with length L, cross-sectional area A, and resistance R. If the length of the conductor cylinder (L) is increased, the resistance will increase. And if the diameter of the conductor cylinder is lowered, the cross-sectional area (A) will decrease so that the resistance will increase. Then it can be formulated as follows:

$$K = \rho \frac{L}{A} \quad (2)$$

With ρ is the resistivity in units (Ωm), L is the length of the conductor cylinder (m), A is the cross-sectional area of the conductor cylinder (m^2), and R is the resistance (Ω). So from equations (1) and (2), we get the resistivity value:

$$\rho = \frac{V\,A}{I\,L} \quad (3)$$

The conductivity (σ) of rocks is the opposite of resistivity ρ with its unit being (Ωm).

$$\sigma = \frac{1}{\rho} \tag{4}$$

In each configuration in the geoelectric method, there is a geometry factor (K), which is the amount of correction of the location of the two potential electrodes to the area of the two current electrodes. The geometry factor is defined in Equation 2. In Equation 1 [12], the geometry factor of the Wenner configuration will be obtained [12], namely:

$$K = 2\pi \left\{\left(\frac{1}{a} - \frac{1}{2a}\right) - \left(\frac{1}{2a} - \frac{1}{3a}\right)\right\}^{-1} = 2\pi \left\{\left(\frac{1}{2a}\right) - \left(\frac{1}{6a}\right)\right\}^{-1}$$

$$K = 2\pi \left\{\left(\frac{2}{6a}\right)\right\}^{-1} = 2\left\{\left(\frac{1}{3a}\right)\right\}^{-1} = 2\pi\{3a\}$$

$$K = 6\pi a \tag{5}$$

Methodology

This research uses the MAE X612-EM Geoelectric tool in Pungguk Pedaro Village, Bingin Kuning District, Lebong Regency. Field measurement has done June 21-23, 2022, with as many as six lines spread across Pungguk Pedaro Village, with a line length of 480 meters. The length of the 480 m line is used to see the distribution and deeper depth of hydrothermal potential due to the deeper penetration of the current. This study uses six lines to see variations in the value of determining hydrothermal potential. Therefore, there is 1 line that cuts 5 lines to validate the value of each line. The measurement line is a straight line by adjusting the conditions of the measurement area. An illustration of measurements in the field can be seen in Figure 5. The results of field measurements are in the form of 2D models, which are processed with pyGIMLI (Python Library for Inversion and Modeling in Geophysics) software.

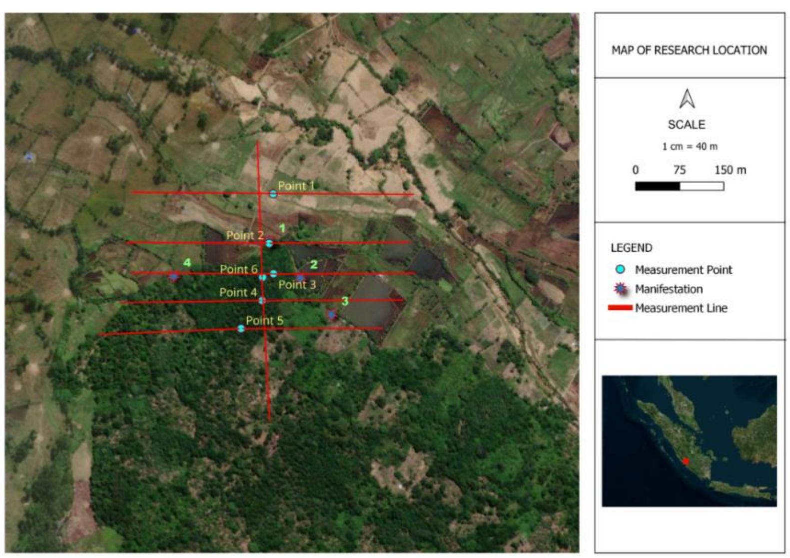

Figure 4. Map of research location

Figure 5. Illustration of field measurements [13]

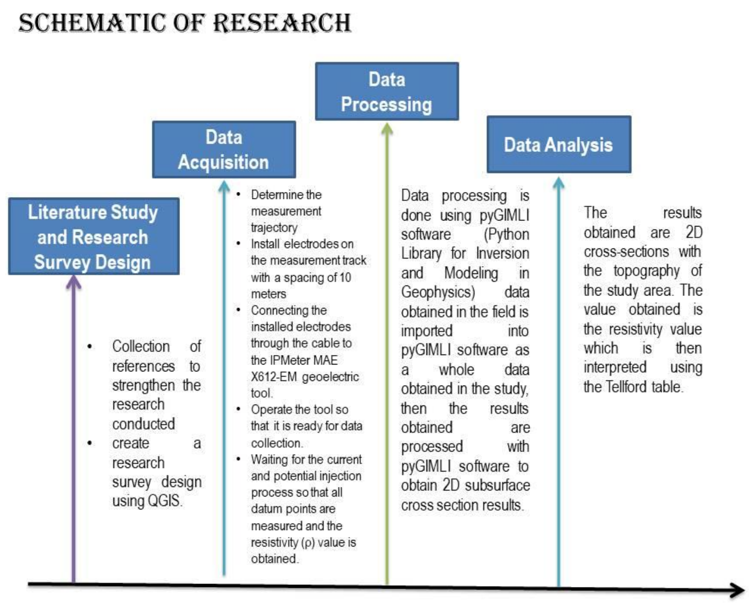

Figure 6. Schematic of research

Result and Discussion

The results of this research measurement using the 2-Dimensional resistivity method in Pungguk Pedaro Village, Bingin Kuning District, were carried out in six passes with the Wenner configuration geoelectric method. This research analyzes each measurement point's current (I) and potential difference (V) data. Electric charge cross-section is obtained from processing resistivity geoelectric data from the field using pyGIMLI (Python Library for Inversion and Modeling in Geophysics) software. The Wenner configuration geoelectric resistivity method obtained a subsurface cross-section in 2 dimensions: resistivity cross-section. Interpret 2D geoelectric data using the table of resistivity values by Telford [14] and adjust to the geological conditions of the data collection location.

The source of geothermal energy comes from magma in the earth. The magma conductively conducts heat to the surrounding rocks. The heat also causes the convection flow of hydrothermal fluid in the pores of the stone, pores of the rock [15]. Then this hydrothermal fluid will move upward but not reach the surface because the rock layer retains it. Surface because an impermeable rock layer owns it. An impermeable layer separates the hydrothermal fluid in the geothermal reservoir from the groundwater. The reservoir is detached from the groundwater, which is shallower. However, until now, it is still uncertain whether the hot water comes from the heating of the bedrock (in the form of magma) below the source point or is just a flow of hot water from other areas. The flow of hot water from another area comes to the surface due to fractures in the rocks that are in the rock that is the flow of hot water.

The subsurface lithology in the study area is relatively the same because the location of the six measurement lines is still close together, namely around the hill where there are volcanic rocks. Pores cause the rock layer in the conductive area of the stone to be filled with fluid or water at high temperatures. This is evidenced by the detection of manifestations on the surface in the form of hot water that appears between hill rocks, warm soil, warm rocks, steamy soil, and small holes containing water grains; the higher the temperature and pressure, the lower the rock's specific gravity value. The 2-Dimensional resistivity model can also display topographic data.

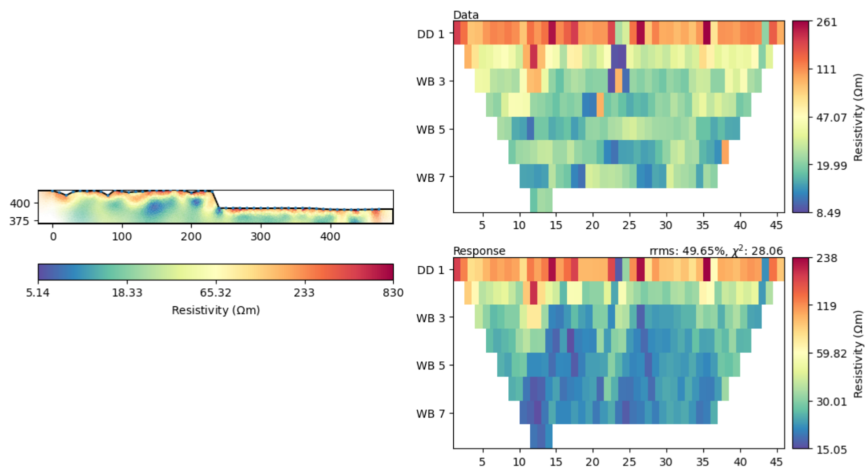

Figure 7. Data processing results of line 1 with topography

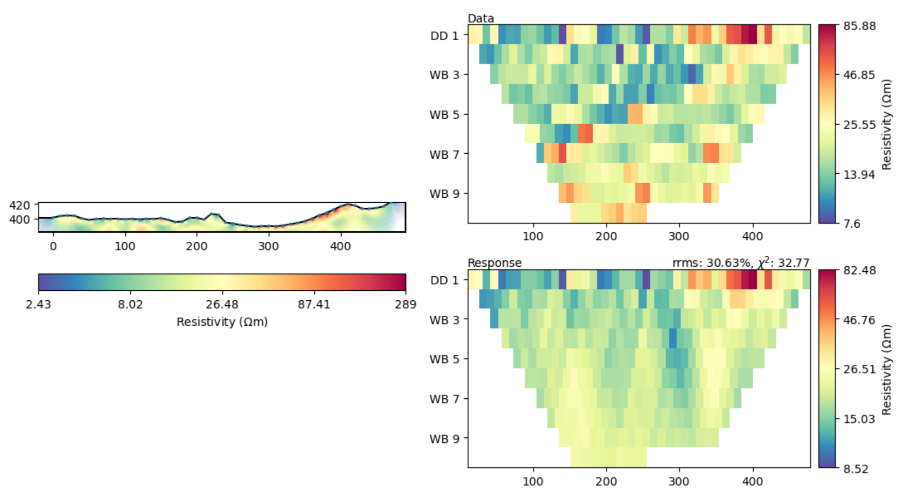

Figure 8. Data processing results of line 2 with topography

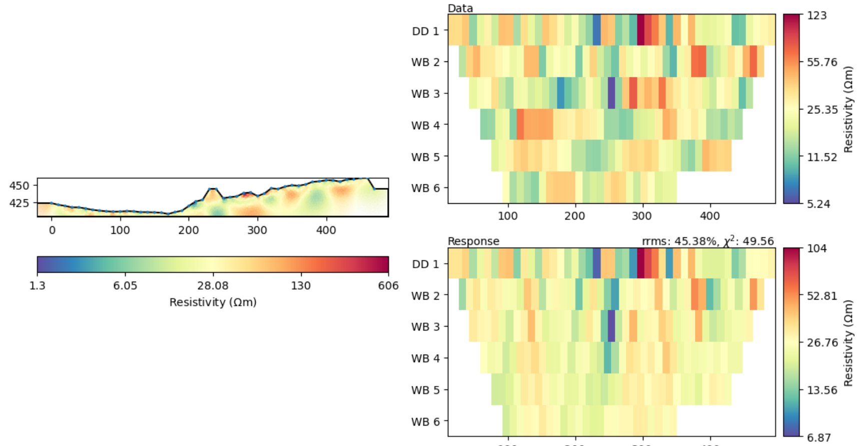

Figure 9. Data processing results of line 3 with topography

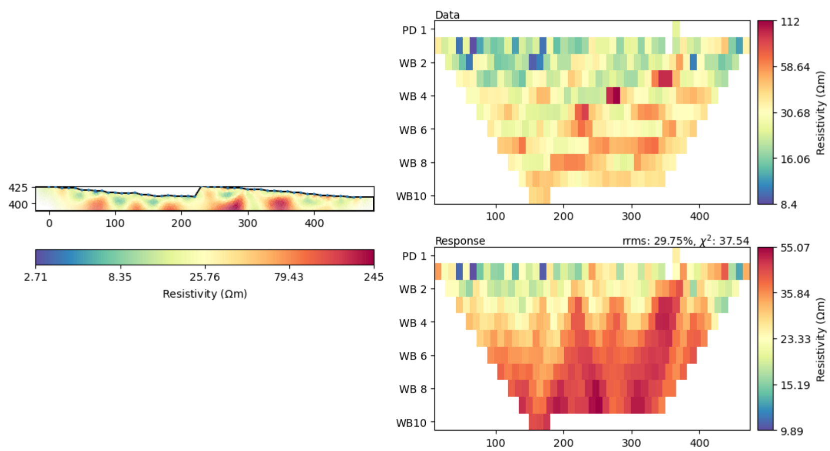

Figure 10. Data processing results of line 4 with topography

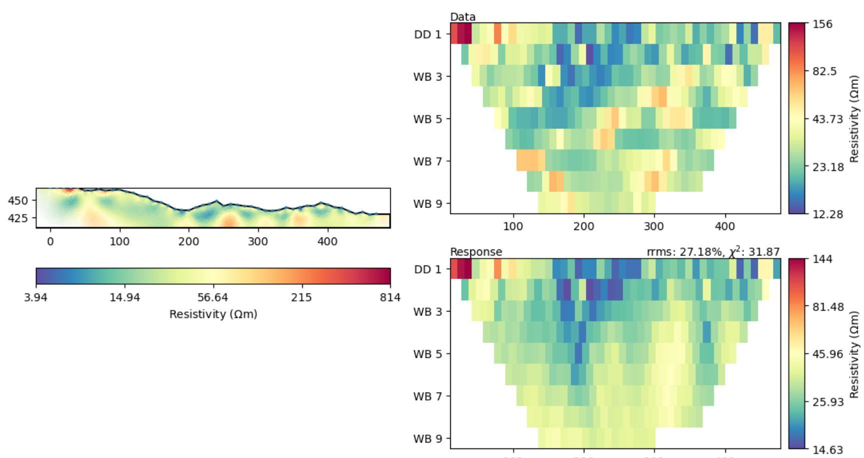

Figure 11. Data processing results of line 5 with topography

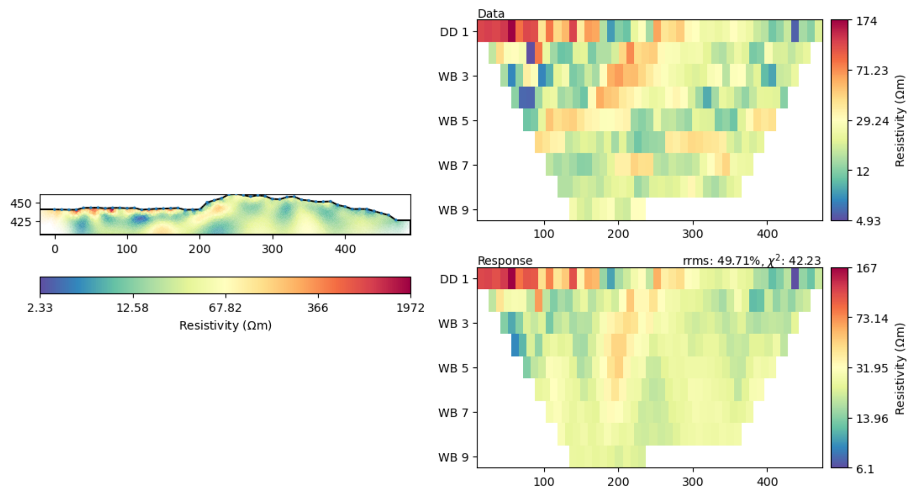

Figure 12. Data processing results of line 6 with topography

This research was conducted in a hilly area where there are community rice fields, and hydrothermal emerges on the surface between volcanic rock fractures. Hydrothermal water that appears on the surface is often used by the community for drinking water needs while on plantations on the hill. The research area is thought to have quite a lot of hydrothermal distribution because the water that appears on the surface has a temperature ranging from (50 – 60)^{o}C. This condition requires research to see hydrothermal and rock types distribution around hydrothermal manifestations. The results of this study provide information to the District Government and the community to find out the presence of hydrothermal in geothermal areas before drilling for geothermal exploitation. The measurement results in each line have a low resistivity value, indicating hydrothermal potential, one of which can be seen in Figure 9. The dominating rock structures in this hydrothermal area are sandy gravel, volcanic breccia, tuff, andesite, basalt and basalt-andesitic sand, silty sand, and clay. Or rocks derived from acidic magma.

In line 1, the water stored in the pores of this rock is called groundwater because line 1 is around rice fields quite far from the potential hydrothermal distribution area. Line 1 is not called hydrothermal because there has been a mixture of steam and water. After conducting research, information on hydrothermal distribution was obtained on lines 2 - 6 because it has a low resistivity value which is at a depth of between (25 – 30) meters below the earth's surface and has geothermal potential even though it is included in the low-temperature reservoir system according to the geothermal grouping [16].

Lines 5 and 6 also show some hydrothermal distribution because the line 5 area is the hilltop of the research area where the foothills have hydrothermal manifestations that appear on the surface. At the same time, line 6 is a track that cuts between line 1 to line 5 to be able to see the hydrothermal distribution more effectively. From this study, it is known that tracks 2-6 have the potential for hydrothermal distribution located at a depth of (25 – 30) meters below the earth's surface, but further investigation is needed to see how prospective the area is for geothermal exploration which can then be exploited.

Table 1. Interpretation in each line site

No	Site	Hydrothermal Potential Electrode Points	Resistivity (Ωm)	depth of hydrothermal potential (m)	Lithology
1	Line 1	-	5.14	-	Groundwater
			18.33		Silty Sand
			65.32		Clay
			233		Sandy Gravel
			830		Andesite
2	Line 2	1	2.43	25	Hydrothermal
			8.02		Groundwater
			26.48		Clay
			87.41		Sandy Gravel
			289		Andesite
3	Line 3	22	1.3	30	Hydrothermal
		26	6.05		Groundwater
			28.08		Clay
			130		Tuff
			606		Andesite
4	Line 4	8	2.71	28	Hydrothermal
			8.35		Groundwater
			25.76		Clay
			79.43		Sandy Gravel
			245		Tuff
5	Line 5	20	3.94	25	Hydrothermal
		23 – 24	14.94		Clay
		31	56.64		Sandy Gravel
			215		Tuff
			814		Basalt
6	Line 6	4 -5	2.33	25	Hydrothermal
		8	12.58		Clay
		12 – 13	67.82		Sandy Gravel
		22 – 23	366		Basalt
			1972		Volcanic Breccia

Conclusion

The results of the potential hydrothermal distribution in Pungguk Pedaro Village, Bingin Kuning District, Lebong Regency, using the Wenner resistivity geoelectric method show that the research area has the potential for evenly distributed hydrothermal distribution in the hilly regions of the study. Each line in the study area has an even distribution of hydrothermal potential and relatively similar rock types. Still, those that appear to have considerable potential are seen in several lines. Locations with good distribution potential include line 3 at a depth of 30 meters, line 5 at a depth of 25 meters, and line 6 at a depth of 25 meters. This area has a high topography with an altitude of (425 – 450) meters.

Line 1 has no potential for hydrothermal distribution because there has been a mixture of hydrothermal water with mountain water, so only groundwater is obtained on this track. While line 2 and line 4 have hydrothermal potential, there are only a few electrode points for the potential distribution.

Acknowledgment

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