

SUBSURFACE SURVEY OF CISARUA LAMPUNG HOT SPRINGS USING GEOCHEMICAL AND GRADIO-MAGNETIC METHOD

SURVEI BAWAH PERMUKAAN MATA AIR PANAS CISARUA LAMPUNG MENGGUNAKAN METODE GEOKIMIA DAN GRADIO-MAGNETIK

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Abstract. The subsurface survey was carried out in Cisarua Hot Springs, South Lampung. Cisarua Hot Springs has a neutral pH and a temperature of about 44 °C. A combination of geochemical and gradio-magnetic methods was used in this research. This research identifies the characteristics of the Cisarua Hot Springs, estimates reservoir temperature, and creates a subsurface model to determine the hot fluid distribution in the study area. According to the geological data, the manifestation of these hot springs correlates with the Lampung-Panjang Fault. The geochemical results show that this type of hot springs fluid is bicarbonate water, and the reservoir temperature is estimated to be around 160 °C. The low gradio-magnetic anomaly is correlated with the distribution of subsurface hot water flow, according to the 3D model of the gradio-magnetic method. The distribution of subsurface hot fluids is in the middle to the eastern part of the research area.

Abstrak. Survei bawah permukaan dilakukan di sekitar Mataair Panas Cisarua, Lampung Selatan. Mataair Panas Cisarua ini memiliki pH netral dan suhu sekitar 44 °C. Kombinasi metode geokimia dan gradio-magnetik digunakan dalam penelitian ini. Penelitian ini mengidentifikasi karakteristik Mataair Panas Cisarua, memperkirakan suhu reservoir, dan membuat model bawah permukaan untuk menentukan distribusi fluida panas daerah penelitian. Berdasarkan data geologi, manifestasi mataair panas ini berhubungan dengan Sesar Lampung-Panjang. Hasil geokimia menunjukkan bahwa tipe fluida mataair panas ini adalah air bikarbonat dan estimasi suhu reservoir sekitar 160 °C. Berdasarkan model 3D metode gradio-magnetik, anomali gradio-magnetik rendah berhubungan dengan distribusi aliran fluida panas bawah permukaan. Distribusi fluida panas bawah permukaan berada di bagian tengah hingga timur daerah penelitian.

1. INTRODUCTION

Indonesia has considerable geothermal potential. According to a recent assessment conducted by the Center for Mineral, Coal, and Geothermal Resources, the Geological Agency of the Ministry of Energy and Mineral Resources, 331 potential areas with 11073 MW of resources and 17506 MW of reserves scattered across 30 provinces (Direktorat Panas Bumi, 2017). There are 93 geothermal potential locations on Sumatra Island, ranging from Aceh to Lampung. One area with geothermal potential is Cisarua, South Lampung Regency, Lampung Province.

There are some researches about geothermal studies that have been conducted in Lampung, such as Husein *et al.* (2015) about tectonic control to the geothermal system of Way Panas, Lampung. Way Panas Geothermal Field is associated with the active Sumatera Fault Zone. Moreover, Permatasari *et al.* (2019) conducted gravity modeling in the Rendingan-Ulubelu-Way Panas Geothermal Field Area, Lampung. According to this research, the high anomaly under Mount Way Panas was interpreted as a tertiary intrusion of granite rocks, while the low anomaly in the northern part was interpreted as a quarter diorite intrusion, which was interpreted as a heat source. Furthermore, Iqbal *et al.* (2019b) about the delineation of recharge and discharge areas in the Natar Geothermal System. According to this research, the recharge area of the Natar Hot Springs is in the Western and Southern parts of the Metro-Kotabumi Groundwater Basin. Iqbal *et al.* (2019a) researched the hydro-geochemistry of Natar Hot Springs. The Natar Reservoir has a temperature of 120–140°C with a depth of 285–400 m, and the geothermal discharge of Natar has undergone water-rock interaction with metamorphic carbonate/ marble under the surface. Next, Santoso *et al.* (2020) identify the flow of hot water in Natar, Lampung. The results obtained are the hot water flows from the gradiometer high anomaly area to the low anomaly area.

The research location is in the Cisarua Area, South Lampung Regency. The discovery of geothermal manifestations as

hot springs is an indicator of the presence of geothermal in this location. A preliminary study in this area has been conducted by Suharno *et al.* (2012) using geological observations. According to this research, hot water that appears on the surface through structures such as faults and fissures is related to the geological state of the Cisarua region, which correlates with the Lampung-Panjang Fault. Because research in this area is minimal, researchers want to conduct research using geochemical and gradiometric methods. The purpose of this research is to identify the characteristics of the Cisarua Hot Springs, estimate reservoir temperature, and create a subsurface model of the study area to determine hot subsurface fluid distribution.

2. LITERATURE REVIEW

2.1. Regional Geology

The regional geology of the Tanjung Karang Area is already mapped by Mangga *et al.* (1993) and shown in **Figure 1**. The bedrock geology in this area was composed of sedimentation of swamps, alluvial, young deposit volcanoes, Lampung Formation, Hulusimpang Formation, Sabu Formation, Tarahan Formation, Menanga Formation, Unconsolidated Gunung Kasih Complex, Way Galih Schist, Dacite Joining, and Dulan Granodiorite (Mangga *et al.*, 1993).

The regional stratigraphy in this area (Mangga *et al.*, 1993) is made up of rocks from the Pre-Tertiary, Tertiary, and Quaternary periods. Schist, gneiss, marble, quartzite, and the Gunungkasih Complex are among the earliest rocks of low-medium metamorphic rock in the tertiary structure. The Gunungkasih Complex consists of schist, graphical pelitic quartz, marble, limestone schist, and orthogenesis. Assuming that this lithological distribution reflects the complex geological state, there is a strong suspicion that the igneous rock formation is the remnants of the Paleozoic magma arc and the remnants of the trench sediment or the groundwater associated with the arc.

The research will be carried out in the Cisarua area of the South Lampung Regency. **Figure 2** shows the location of hot springs in

the study area. According to the geological map and preliminary research by Suharno et al. (2012), the manifestation of the Cisarua Hot Springs is located on the Lampung-Panjang Fault with a northwest-southeast direction. Old Hot Springs are no longer active due to drilling in Young Hot Springs. According to direct observations in the field

and a previous study (Suharno et al., 2012), it shows that the Old Cisarua Hot Springs has travertine sintered deposits with a diameter of about 12 m. In comparison, the Young Hot Springs have a diameter of about 1.5 m. The hot springs manifestation is also surrounded by sintered travertine deposits.

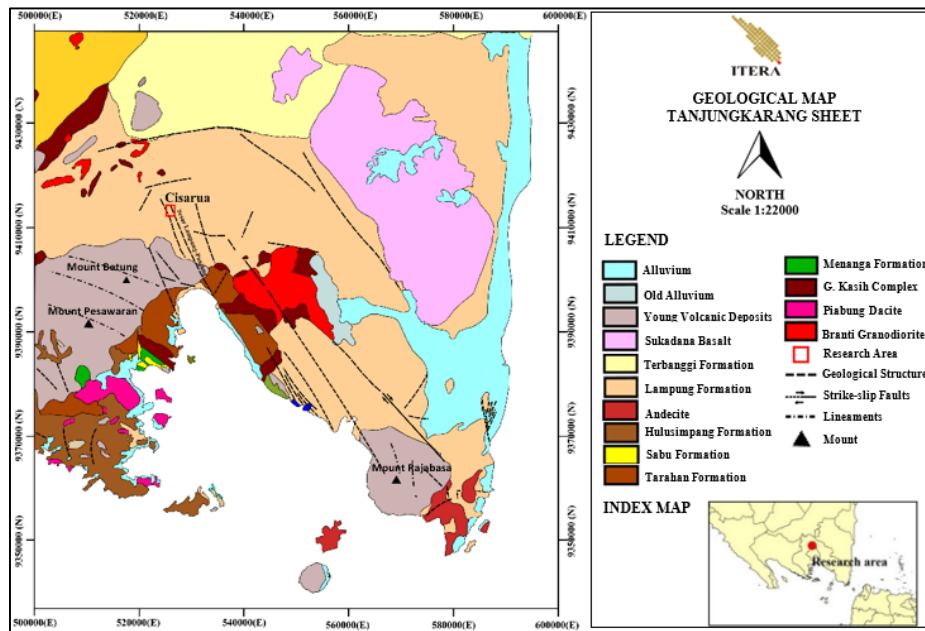


Figure 1. Geological Map of Tanjung Karang (Modified from Mangga et al. (1993)).

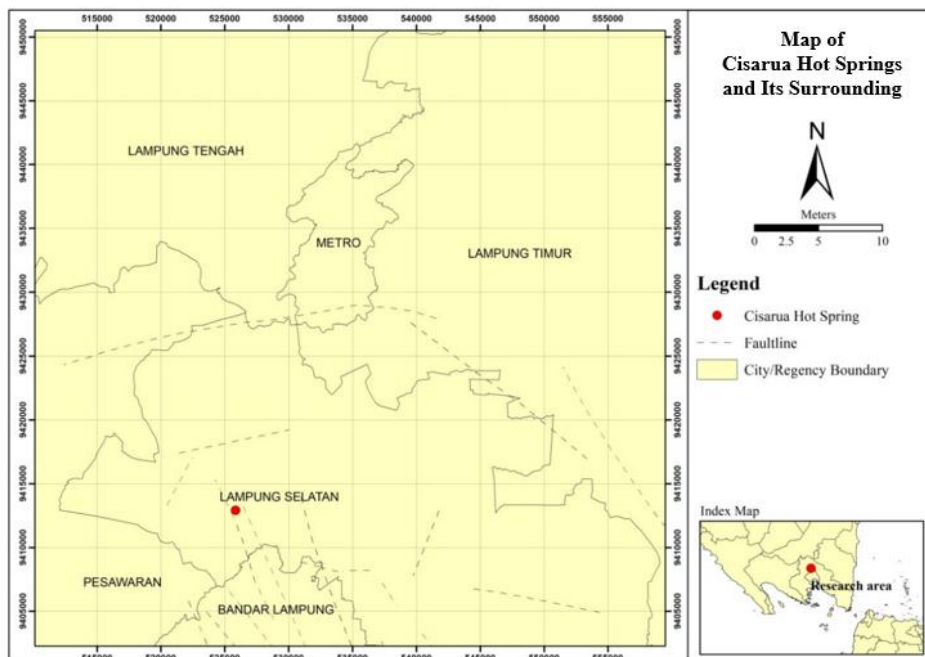


Figure 2. Map of Cisarua Hot Springs and Its Surrounding.

2.2. Geothermal Systems

Du et al. (2005) researched variations of geothermometry and chemical-isotopic compositions of hot spring fluids in the Rehai Geothermal Field, Southwestern China. According to various geothermometers, the estimated temperatures of the geothermal reservoirs are from 69 °C to 450 °C, and the estimated subsurface reservoir temperature is 250–300 °C. Moreover, they show the contributions of mantle fluids and shallow crust fluids in the Rehai Geothermal Field varied with time, which was associated with variations of chemical and isotopic compositions and reservoir temperatures. Furthermore, Alam et al. (2019) researched hydrogeochemistry and isotopic characteristics at Indonesia's Cidanau Geothermal Field. According to the research, geothermal waters were identified mainly as Na-Cl-HCO₃ types of water, and the pH of the waters was close to neutral. The temperature of the hot-water discharges ranged from 32.2 °C to 61.1 °C. Moreover, they also showed a conceptual model of the Cidanau Geothermal Field Hot Springs.

Purnomo and Pichler (2014) discuss geothermal systems in Java, including determining the temperature of geothermal reservoirs by identifying water chemistry. Moreover, they also showed that the geothermal system in Java was affected by the faults system. Furthermore, Purnomo and Pichler (2015) researched the geothermal system on Bali Island.

DiFrancesco et al. (2012) reviewed gravity gradiometry in non-traditional applications. Modeling and analytic scenarios for detecting and characterizing aquifers using gravity and gradiometry, monitoring CO₂ storage sites, geothermal exploration, and enhanced oil recovery monitoring.

3. METHODS

The method used in this study is a combination of the geochemical and gradio-magnetic methods. The geochemical survey is carried out by mapping coordinates and taking water samples directly into the Cisarua Hot Springs. The geochemical analysis is carried out using the Atomic

Absorption Spectrometry method based on laboratory testing. Atomic absorption spectrometry (AAS) is a technique in which free gaseous atoms absorb electromagnetic radiation at a specific wavelength to produce a corresponding measurable signal (Ivanova, 2005). The absorption signal is proportional to the concentration of the free atoms present in the optical path (Ivanova, 2005).

The elements tested include Na, K, Ca, Mg, Cl, SO₄, and HCO₃. The geochemical data is then analyzed and plotted on a ternary diagram to determine the type of hot spring and estimate reservoir temperature. The geothermometer Na-K-Mg (Giggenbach, 1991) was used to estimate the subsurface temperature using equation (1) for the neutral chlorite water. After that, a geothermometer K-Mg was used for the bicarbonate water using equation (2). The equations (1) and (2) are as follows:

$$t^{\circ}\text{C} = \frac{1390}{\log\left(\frac{\text{Na}}{\text{K}}\right) + 1.75} - 273 \quad (1)$$

$$t^{\circ}\text{C} = \frac{4410}{14 - \log\left(\frac{\text{K}^2}{\text{Mg}}\right)} - 273 \quad (2)$$

The gradio-magnetic approach is measured using a magnetometer and a gradiometer combination. The gradio-magnetic method is comparable to the magnetic method in its acquisition, processing, and interpretation of data. The difference is in the number of sensors used, with the gradio-magnetic method applying two magnetometer sensors at the same time. The use of two sensors has the purpose of reducing daily variation correction. The gradio-magnetic is a measurement that uses two magnetometer sensors to determine the difference in data between the two sensors. Coulomb's law gives the basic concept of magnetic force \mathbf{F} (Telford et al., 1990):

$$\mathbf{F} = \frac{p_1 p_2}{\mu r^2} \mathbf{r}_1 \quad (3)$$

Where \mathbf{F} is the force on p_2 , the poles of strength p_1 and p_2 are r apart, μ is the magnetic permeability, and \mathbf{r}_1 is a unit vector directed from p_1 toward p_2 (Telford et al., 1990).

Gradio-magnetic surveys are usually calculated from the gradient \mathbf{F} of the

magnetic contour map. Measuring the vertical gradient directly in the field has a lot of advantages (Telford et al., 1990). It's just a matter of taking two readings, one above the other. Then there's the vertical gradient:

$$\frac{\partial F}{\partial z} = \frac{F_2 - F_1}{\Delta z} \quad (4)$$

Where F_2 and F_1 are readings at the higher and lower elevations, and Δz is the separation distance (Telford et al., 1990).

Figure 3 shows the design of a gradio-magnetic survey conducted in the Cisarua area. A total of 93 gradio-magnetic measuring stations with a distance between stations of 25 m were set up around the Cisarua Hot Springs, which cover an area of around 39375 m². A magnetometer sensor is separated from another by about 1 m. The gradio-magnetic data is processed to create a subsurface model of the research area.

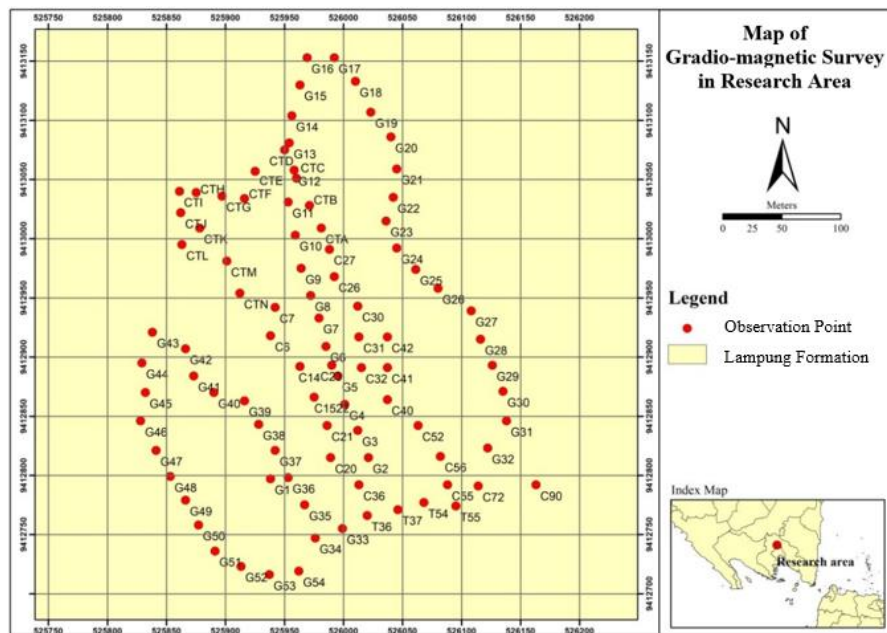


Figure 3. Design of the Cisarua Gradio-magnetic Survey.

4. RESULTS AND DISCUSSION

UTM-X 525897 m and UTM-Y 9413036 m are the Old Cisarua Hot Springs coordinates. UTM-X 526037 m and UTM-Y 9412891 m are the Young Cisarua Hot Springs coordinates. The Cisarua Hot Springs has a neutral pH and a temperature of roughly 44 °C based on direct observations and measurements in the field. **Table 1** shows the results of the Cisarua sample's water chemistry study. The Cisarua Area has only one active fluid manifestation, the Young Cisarua Hot Springs. While the Old Cisarua Hot Springs' fluid manifestations have dried up, there is still evidence of sintered travertine.

The results of the geochemical data processing are shown in **Figures 4** and **5**. According to the Cl-SO₄-HCO₃ ternary diagram (Giggenbach, 1991) in **Figure 4**, the

Cisarua Hot Springs type is bicarbonate water. This result is also valid with Iqbal et al. (2019a) research. This indicates that the fluid has come into contact with rocks near the surface or in the shallow subsurface (Nicholson, 1993). The sintered travertine deposits found around the hot springs support these results. Based on the Na-K-Mg ternary diagram (Giggenbach, 1991) in **Figure 5**, the estimated reservoir temperature of the research area is around 160 °C.

The gradio-magnetic data processing results can be shown in **Figures 6** and **7**. The hot springs in the research area have a low gradio-magnetic anomaly, as shown in **Figure 6**. **Figure 7** shows the 3D low anomaly gradio-magnetic modeling results. We got a depth of roughly 135 m from that modeling

and showed a low anomaly gradio-magnetic distribution. Because hydrothermal processes can significantly reduce rock magnetization either through thermal demagnetization or by altering magnetic minerals to more minor magnetic minerals, magnetic or gradio-magnetic anomalies are helpful in the delineation of geothermal systems (Tontini et al., 2016). As a result, hot objects or fluids will become demagnetized or lose their magnetic properties. Therefore, the low gradio-magnetic anomaly is associated with the subsurface hot fluid distribution. The subsurface fluid distribution area is in the middle to the east part of the research region.

The distribution of hot bicarbonate fluid is a shallow reservoir or obtained at a depth of 20 to 135 m, according to 3D gradio-magnetic modeling and geochemical result. The gradio-magnetic results are consistent with previous research by Santoso et al. (2020), which showed a hot water distribution in the center and southeast of the research area.

Using the gradio-magnetic method, this research focuses on the Cisarua Hot Springs. Furthermore, more comprehensive and detailed measurements are required. Therefore, additional research studies such as the magnetotelluric (MT) method and drilling are required to ensure the existence of a shallow reservoir in the research area.

Table 1. Water Chemistry Result.

No	Sample	Code	pH	T ° C	Na ppm	K ppm	Ca ppm	Mg ppm	Cl ppm	SO ₄ ppm	HCO ₃ ppm
1	Cisarua	Ci	7	44	826	87	12.4	1.3	601	160	1297

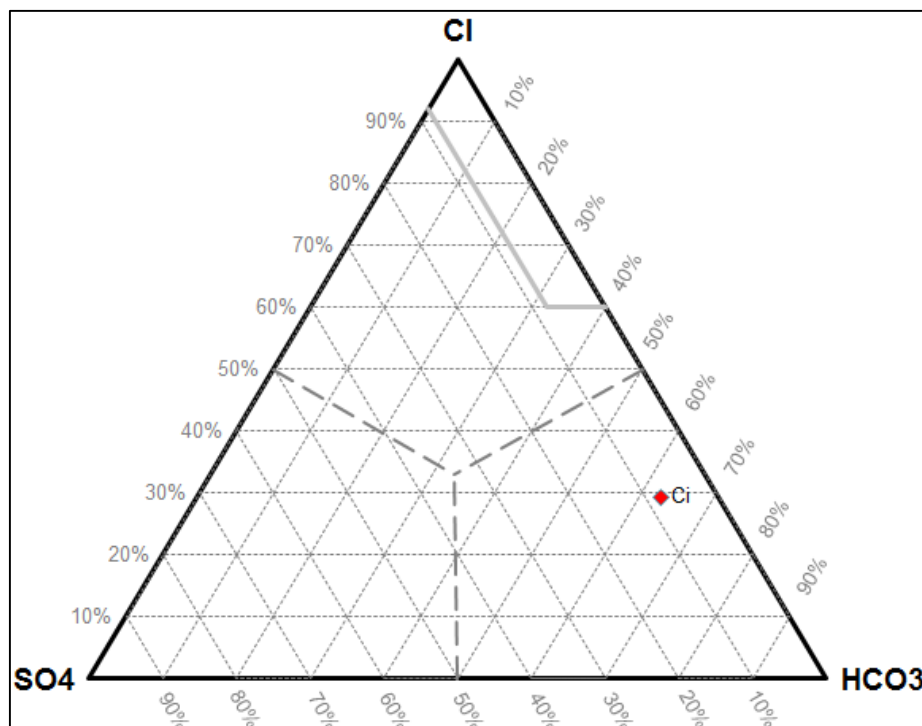


Figure 4. Type of Hot Spring Research Area (Modified from Giggenbach (1991)).

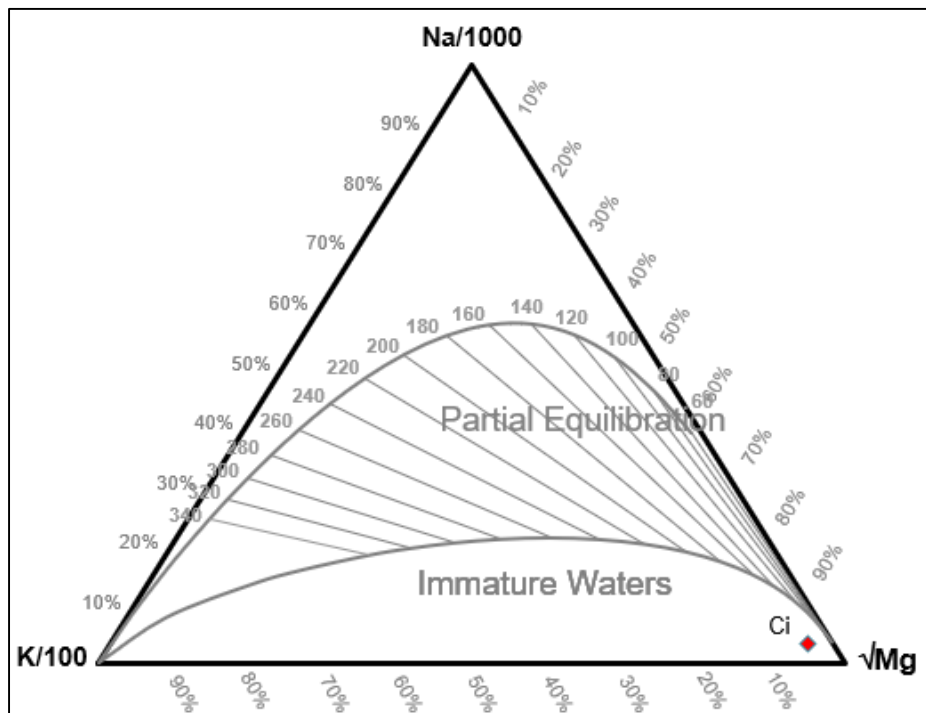


Figure 5. Estimation of Reservoir Temperature in the Research Area (Modified from Giggenbach (1991)).

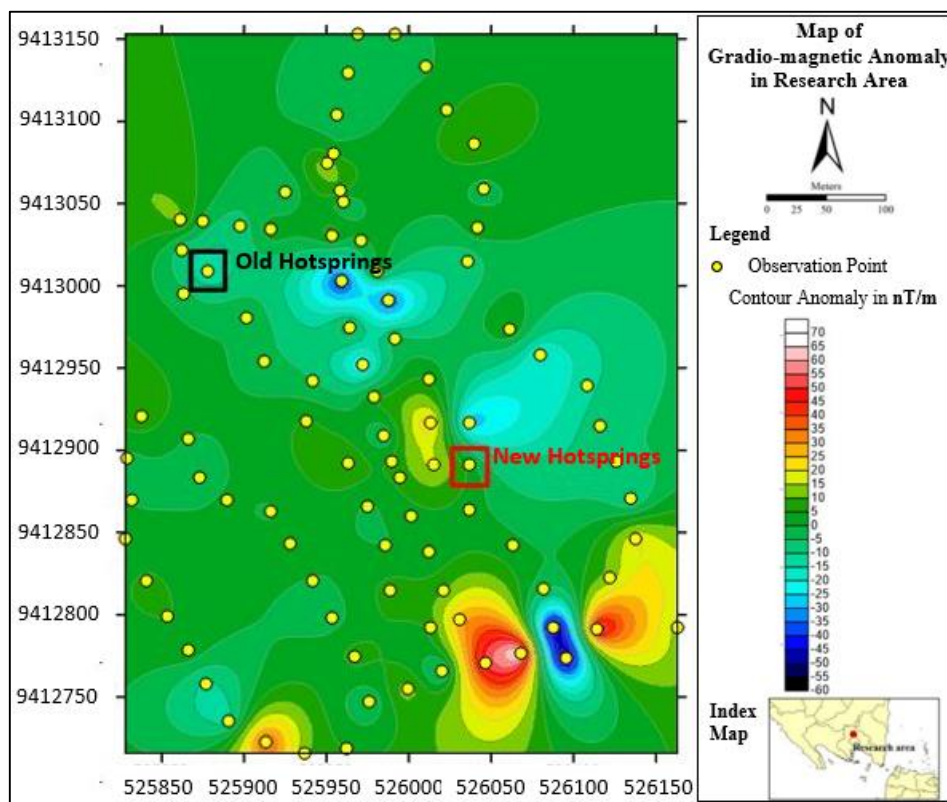


Figure 6. Gradio-magnetic Data Processing Result.

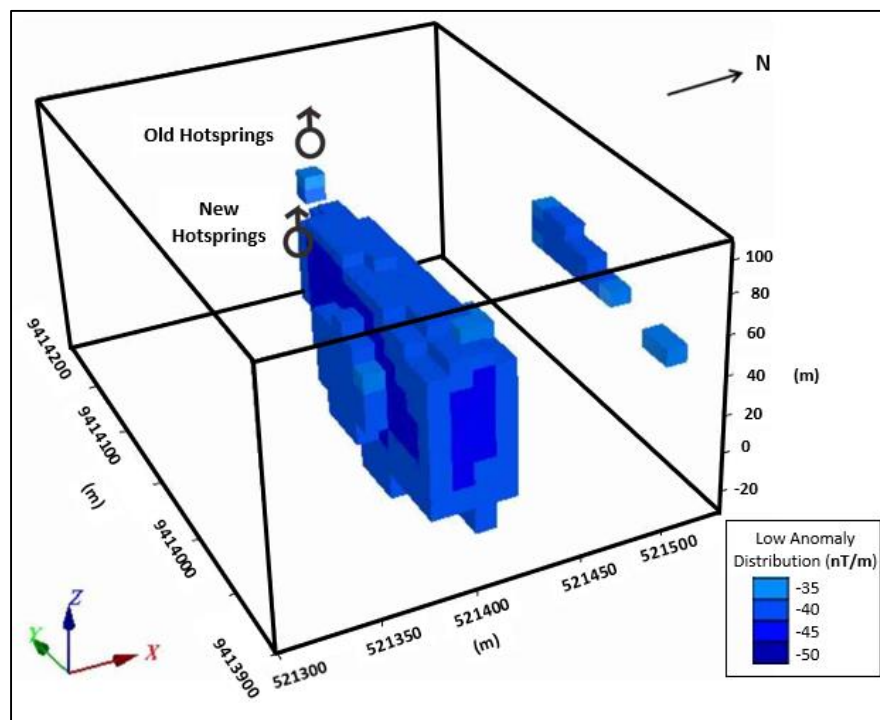


Figure 7. Results of 3D Low Anomaly Gradio-magnetic Modeling in the Research Area.

5. CONCLUSION

The following are some of the findings of this study:

- Geochemical results show that the Cisarua type of Hot Springs is bicarbonate water, and the estimated reservoir temperature is around 160 °C.
- The gradio-magnetic results show that the distribution of hot subsurface fluids is in the middle to the east part of the research area.

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