Identification 2D Modelling of Subsurface Structure Geothermal Prospect Area by Gravity Method: Case Study in Tanuhi, South Kalimantan

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Abstract. Geothermal potential in Kalimantan is rare because the island does not have an active volcano. In addition, when viewed from the subsurface structure, Kalimantan Island is in medium-low enthalpy with hot sprung as one of the geothermal potentials, which are generally in the immature water zone. One of the areas is Tanuhi Hot Springs, South Kalimantan. Therefore, this study was conducted to determine the geothermal system of the area using the gravity method. The gravity data processing stage produces the CBA value (Complete Bouguer Anomaly) which is then separated using the Butterworth filter method. Judging from the CBA map, the results of the qualitative interpretation show that the geothermal potential is in a low anomaly with a value of (-19.4 mgal) – (-14.2 mgal) which is marked in the dark blue. While the results of the quantitative interpretation resulted in the cross-sectional modeling of SW-NE (Southwest – Northeast) and NW-SE (Northwest - Southeast) with a total of 3 layers. The layer consists of granite, clay, and sand mixed with granite. Both models are dominated by sand mixed with granite with the density value at cross-section SW-NE and cross-section NW-SE is the same, namely 2770 kg/m³.

1. Introduction
Plate movements in the territory of Indonesia are very active where Indonesia is located between three plate encounters such as the Eurasian, Indo-Australian, and Pacific Plates. From these plate movement activities, it forms a diverse geographical condition that causes Indonesia to have abundant natural resources. One of these natural resources is the potential of geothermal resources. This potential can be used as environmentally friendly alternative energy to replace non-renewable energy such as coal, oil, and natural gas.

As the economy and population grow, the need for electrical energy is increasing. Of course, this increase in electrical energy does not have to depend on fossil fuels, when viewed from the geographical condition of Indonesia, which is traversed by the ring of fire, the potential for geothermal sources is abundant, this happens because the geothermal system is formed due to ongoing volcanic processes. The utilization of this geothermal resource is more environmentally friendly because it can reduce carbon dioxide emissions from burning fossil fuels. Geothermal is also a clean energy that does not require carbon-intensive fuel to operate power plant. Therefore, geothermal energy can support Indonesia’s target in achieving emission reduction of greenhouse gas (GHG) to 29 percent by 2030 [1].
One of the areas in Indonesia that have the potential for geothermal resources is Tanuhi, South Kalimantan, Hulu Sungai Selatan Regency. If viewed from the geological setting, it is included in the Muria-Meratus subduction pathway in the limestone age, which consists of steep, undulating hills dominated by plutonic rock types with limestone composition of granitic and Cretaceous-Miocene sedimentary rocks as well as alluvial deposits in plain areas, geological structure The developing fault is dominated by a normal fault with a southwest-northeast direction known as the Meratus Pattern and a dextral horizontal fault with a northwest-southeast trend called the Andang pattern. [2] The existence of a geothermal manifestation on the surface indicates the presence of geothermal below the surface with a phase change in the hydrothermal geothermal system in the passage of fluids to the earth's surface, causing different types of geothermal manifestations as indicated by the presence of hot springs, geysers, mud pools or hot mud pools, and hot tubs. [3] In this study, geothermal manifestations are in the form of hot springs which are used as hot spring baths in Tanuhi Village, South Kalimantan.

![Figure 1. District Boundary of Hulu Sungai Selatan.](image)

To find out the state of the geothermal system, a geophysical method is needed that can provide information about the structure below the earth's surface. In this study, the geophysical method used is the gravity method by looking at the differences in rock density found in Tanuhi Village, South Kalimantan.

### 1.1 Geothermal System

Geothermal sources can be formed due to plate movements that can cause subduction zones and the formation of volcanic areas. The formation process occurs when rainwater that is absorbed through cracks in the soil will gather in the reservoir rock. The groundwater will go through a healing process that comes from the main heat energy source, namely magma.

Geothermal systems are formed as a result of heat transfer from surrounding heat sources that occur by conduction and convection. Conduction heat transfer occurs through rocks, while convection heat transfer occurs due to contact between water and a heat source that can form hot fluid in the reservoir. The existence of a geological structure in the form of a fault that cuts through the reservoir,
causes this hot fluid to come out to the surface in the form of geothermal manifestations, such as hot water. [5]

![Illustration of Geothermal System](image)

**Figure 2. Illustration of Geothermal System.** [5]

### 1.2 Principle of Gravity Method

The basic principle of the gravitational method is to use the basic theory of Newton's law of gravity, where the force between two particles of mass $m_1$ and $m_2$ directly proportional to the product of the masses and inversely proportional to the square of the distance between the centers of mass. [7] This is shown in the equation:

$$F = \gamma \frac{m_1 m_2}{r^2} r_1$$

(1)

Where $F$ is the force exerted by a particle of mass $m_1$ and $m_2$, $r^2$ is the distance between the two particles, $r_1$ is a unit vector, and $\gamma$ is the gravitational constant which has the value $6.672 \times 10^{-11}$ Nm$^2$/kg$^2$ in international units and $6.672 \times 10^{-8}$ dyne cm$^2$/g$^2$ cgs units. [7]

In the gravity method, the measured quantity is the acceleration of the earth's gravity by producing various kinds of corrections such as earth tide correction, buoyancy correction, latitude correction, free air correction, Bouguer correction, and field correction. After calculating the corrections in data processing will produce a complete bouguer anomaly value. The acceleration due to Earth's gravity can be shown by the equation:

$$g = \left(\gamma \frac{M_e}{R_e^2}\right) r_1$$

(2)

Where $M_e$ and $R_e$ are the mass of the earth and the radius of the earth.

### 1.3 Bouguer Correction

Bouguer correction is taken into account because there is a pulling effect of the rock mass of the station and datum plane, assuming it has an infinite radius with a thickness $h$ (meters) and a density $\rho$ (g/cc). [7] This correction is made to eliminate the difference in height $h$ (meters) without ignoring the mass ($\rho$) below it. The height difference will result in the influence of the mass below the surface which affects the magnitude of the acceleration of gravity at the very point. [9]

$$BC = 0.04191 \rho h$$

(3)
1.4 Terrain Correction

Field correction is carried out because at the measurement point there are topographic effects and large elevation differences, such as hills and valleys around the measurement station, so a simple bouguer anomaly correction is carried out, where the topography affects the reading because gravity is conservative and reduces the reading value from the ideal state. [8]

\[ \delta g_T(r, \theta) = \gamma \rho \theta \left( (r_0 - r_i) + \sqrt{r_i^2 + \Delta z^2} - \sqrt{r_0^2 + \Delta z^2} \right) \]  (4)

\( \delta g_T \) is the field correction (mGal), \( \gamma \) is the universal gravitational constant, \( \Delta z \) is the difference in elevation of the compartment (m), \( r_0 \) and \( r_1 \) is the radius of the outer and inner circle (m), and \( \theta \) is the angle formed by the compartment (degrees).

1.5 Butterworth Filter

Is a method of smoothing a signal or image. Which can help eliminate noise, because noise is caused by high frequencies. In the function Butterworth lowpass filter (BLPF) with a value of the order to n, and with a cutoff at the \( D_0 \) distance from the origin. [10] Defined as:

\[ H(u, v) = \frac{1}{1 \left[ D(u, v)/D_0 \right]^{2\pi}} \]  (5)

Where \( D(u, v) \) is the distance between the points \( (u, v) \) in the frequency domain and the center of the frequency rectangle which is written in the following equation:

\[ D(u, v) = \left( \left( u - \frac{\pi}{2} \right)^2 \right) + \left( v - N/2 \right)^{1/2} \]  (6)

2. Method

This research was conducted from March 28 to April 30, 2021. The research location for the Tanuhi hot spring is in the Hulu Banyu Village, Loksado District, Hulu Sungai Selatan Regency. The geographical location of Hulu Sungai Selatan Regency is located between 115° 27' 8.48" East Longitude, and 2 47' 28.12" South Latitude. When viewed based on the topography of Hulu Sungai Selatan Regency, it is located at an altitude of 0-7 meters and a slope of 0-2%, based on an altitude from sea level, 58.3% of the Hulu Sungai Selatan Regency are at an altitude of 0-7 meters and only 0.9% is at an altitude of over 1000 meters. [7]
Figure 4. Regional Geological Map of Tanuhi, South Kalimantan. [1]

The processed data are secondary data consisting of gravity and topographic data. Both of these data can be obtained by accessing the TOPEX website, with a total of 3904 data generated. The gravity data only require bouguer correction and field correction because the resulting data has been corrected in the form of FAA (Free Air Anomaly) data. In data processing requires some software, including Microsoft Excel and Oasis Montaj. So to calculate the bouguer and terrain correction values, Microsoft Excel software is needed to get the complete bouguer anomaly (CBA) value. While the oasis montaj software is used for making CBA contour maps, 2D modeling of geothermal systems, determining the residual anomaly slice point and separating regional and residual anomalies using the Butterworth filter method because it is easier to use for clear regional and residual trend selection. In addition, in 2D modeling, forward modeling is used to observe the gravitational response caused by the modeling.
Figure 5. Research Flowchart
3. Result and Discussion

3.1 Qualitative Interpretation
In the data processing process, after obtaining the gravity correction value, the CBA (Complete Bouguer Anomaly) value will be obtained. The CBA value is depicted through a CBA contour map which produces an overview of the topographical conditions in the study area.

![CBA Contour Map](image)

**Figure 6. CBA Contour Map (Complete Bouguer Anomaly)**

Based on the interpretation of the CBA contour map, there are three anomalous patterns in the research area of Tanuhi Village, South Kalimantan. The three patterns are indicated by gravity anomaly values ranging from low, medium, to high. The first anomalous pattern with low anomaly values ranged from (-194) mgal – (-6.3) mgal. The second anomaly pattern with moderate anomaly values ranged from (-4.7) mgal – (32.9) mgal, and the third anomaly pattern with high anomaly values ranged from 34.6 mgal – 46.7 mgal. This research was conducted with the main focus on areas that have low anomalous values, namely the research area indicated in dark blue with an anomaly value of -194 mgal. This research area is close to Mount Meratus which was formed due to volcanic and tectonic activities.
3.2 Depth Estimation and Separation Anomalies

Gravity data processing will produce a complete Bouguer anomaly value, where the resulting anomaly value will be used to identify the subsurface geological conditions in the research area. The complete Bouguer anomaly value consists of regional and residual anomalies, so it is necessary to separate the two anomalies. In addition to the separation of anomalies, it is necessary to estimate the depth of regional and residual anomalies in the study area, so the first step to be taken is to find the depth value obtained by analyzing the RAPS curve. Based on the RAPS curve, the blue color indicates a regional anomaly with the line equation $y = -240.73x + 10.18$, so the regional depth obtained is 19 km or deeper. While the red line shows the residual depth.

![Radial Average Power Spectrum](image)

**Figure 7.** Radial Average Power Spectrum

After getting the depth value for the regional and residual anomalies, the next step is to separate the anomalies using the Butterworth filter method which produces a contour map in the form of a regional anomaly map and a residual anomaly map. As seen from Figures 8.a and 8.b, there is a difference between regional and residual, where the resulting regional anomaly map is smoother with values ranging from (-17.3) mgal – (45.3) mgal, while the resulting residual anomaly map is coarser. With values ranging from (-21.0759) mgal – (16.8485) mgal. The difference is because the regional anomaly map has a wider and deeper area when compared to the shallower residual anomaly map.

![Regional Anomaly Map](image)

![Residual Anomaly Map](image)

**Figure 8.** (a) Regional Anomaly Map, (b) Residual Anomaly Map
3.3 Quantitative Interpretation

Quantitative interpretation is carried out to see the modeling originating from the gravity anomaly that has been generated to determine a subsurface model, by slicing the residual anomaly to produce 2 cross-sections, namely NW - SE (Northwest - Southeast) and SW - NE (Southwest - Northeast).

![Figure 9](image1.png)  
**Figure 9.** (a) NW-SE Residual Anomaly Section, (b) NW-SE Section 2D Modeling

Figure 9 is a cross-sectional model of NW-SE which consists of 3 layers below the earth's surface. The first layer is shown in brown, the layer contains clay rock at a depth of about 0 km – 6 km, with a clay rock density value of 1960 kg/m$^3$. In this layer, clay rock is a rock cover whose role is to protect the geothermal reservoir that is formed, because it can prevent fluid from coming out. The second layer is shown in white, the layer contains sandstone mixed with granite. This layer has a density value of 2770 kg/m$^3$, which serves as a reservoir of hot water that forms below the earth's surface. And the third layer is shown in gray, the layer contains granite rocks with a density value of 2790 kg/m$^3$. This third layer helps the formation of a geothermal reservoir because the rock is exposed to heat from magma, so it can heat something above its surface, in this case, a hot water reservoir.

![Figure 9](image2.png)  
**Figure 9.** (a) SW-NE Residual Anomaly Section, (b) SW-NE Section 2D Modeling

Figure 8 is a cross-sectional model of SW-NE which consists of 3 layers below the earth's surface. The first layer is shown in brown, which has a density of 1980 kg/m$^3$ is estimated that the first layer is at a depth of about 0 km - 8 km, this layer contains clay rock which functions as a rock cover to protect the geothermal reservoir that is formed because it can prevent fluid from escaping. The second layer is shown in white, which has a density 2770 kg/m$^3$ it is estimated that the second layer is at a depth of about 2 km – 15 km, this layer contains sandstone mixed with granite. In this layer, a hot water reservoir will be formed. And finally, the third layer is shown in gray, which has a density of
2810 kg/m$^3$ it is estimated that the third layer is at a depth of 12 km - 16 km, this layer contains granite which has a role in the formation of a geothermal system because in this layer the rock will be exposed to heat from magma so that this layer also functions in heating things. Which is above the surface, in this case, is a hot water reservoir.

### 4. Conclusion

From the results of the qualitative interpretation, it produces a picture through a complete Bouguer anomaly map of the research area which is divided into three anomalous patterns, namely, high, medium, and low anomalies. In this study, it is shown in areas that have a low anomaly with a value of – 19.4 mgal which is shown in dark blue.

Meanwhile, the results of the quantitative interpretation provide a 2D depiction of the rock layers below the ground surface, from slicing residual anomaly resulting in a cross-section of SW-NE (Southwest – Northeast) and NW-SE (Northwest - Southeast) with a total of 3 layers. This layer consists of granite, clay, and sand mixed with granite. Both models are dominated by sand mixed with granite with the density value at cross-section SW-NE and cross-section NW-SE is the same at 2770 kg/m$^3$.

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