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Two dimensional modeling (2D) gravity method for interpreting subsurface structure of mount Merapi

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Abstract. Mount Merapi is one of the active volcanoes in Indonesia. The characteristics of this mount are explosive and eruptive. Moreover, its eruption causes lava floods. Its last eruption took many victims, and they were both dead and injured. They lost belongings and anything surroundings as well. Considering the negative impacts, research is needed to determine the subsurface structure of Mount Merapi as a disaster mitigation measure. One method that can be used is the gravity method. The gravity method is a geophysical method with an interpretation based on the different density of masses obtained from the Earth's gravity acceleration data. In this research, an interpretation of the results of two-dimensional modeling will be performed. Research data is secondary data obtained from satellites. The research uses a literature study method on Mount Merapi by processing gravity data to obtain Bouguer anomalies, separating Bouguer anomalies into local and regional anomalies using MagPick and Surfer software, and two-dimensional modeling to determine density value density of subsurface mass using Grav2dc software. The results obtained consist of lithological interpretation consisting of basalt-andesite rocks, pyroclastic rocks, and magma chamber.

1. Introduction

Indonesia is a country that has many volcanoes, both active and inactive, on land and at sea. Volcanoes in Indonesia stretch from west to east from Sumatra, Java, to Sulawesi. All of these mountains are in a series so that the characteristics of each mountain are more or less the same.

Active volcanoes in Indonesia are divided into three groups based on historical eruptions, and those are; type A (79 volcanoes) are volcanoes that have erupted since 1600, type B (29 volcanoes) are mountains that have erupted before 1600, and type C (21 mountain fruit) is a solfatara and fumarole field. Type A is still classified into eight types, namely Mount Tambora type (caldera eruption), Mount Batur (post-caldera), Mount Kelud (crater lake), Mount Papandayan (crater wall collapse), Mount Merapi (incandescent lava), Mount Agung (open crater), Sangeangapi (melt lava), and Gunung Anak Krakatau (underwater volcano) [1].

One of the active volcanoes in Indonesia is Mount Merapi. The word Merapi comes from the word Meru which means mountain and fire, so that Merapi means is a volcano [2]. Mount Merapi is a volcano with a strato-volcanic type with a height reaching 2997 m. The geographical position of Mount Merapi is at latitude 7^0 32' 5 "S and longitude 110^0 26" 5 "E with administrative areas in the provinces of Central Java and D.I. Yogyakarta. This mountain is formed geodynamically in the archipelago due to the Indo-Australian plate's subduction meeting with the Asian plate.

Mount Merapi is at the intersection of the north-south trending fault system [3]. This fault system is spread out through Mount Ungaran, Mount Gadjah Mungkur, Mount Suropati, Mount Andong, Mount Telomoyo, and Mount Merbabu. Mount Merapi is a stratovolcano type with the dominant constituent rock basalt-andesite with SiO2 composition ranging from 50-58%. Mount Merapi rocks are composed of plagioclase, the main mineral constituent of Merapi rocks with about 34%, olivine, pyroxene, magnetite, and amphibole [2].

This volcano has explosive eruptive characteristics, and eruptions often cause lava floods [4]. The particular characteristic of Mount Merapi when it erupts is that it produces hot clouds of heat called wedus gembel in the Javanese term. According to [4], this hot cloud is a primary danger because it consists of gaseous elements, lumps of rock, and volcanic ash preceded by lava flows and lava dome collapse. In 1930 and 1961, the eruption of Mount Merapi produced hot clouds up to 12 km to the southwest. In 1998, this hot cloud reached 30000°C, which can blemish human skin [2].

The last eruption of Mount Merapi, which was in 2010, caused huge losses. According to [4], 2,447 houses were severely damaged, and 6,472 houses were moderately damaged. Moreover, casualties also occurred. Three hundred thirty-two people died, and 1,705 people were injured, and 4,874 people experienced psychological disorders.

Geophysical exploration is needed to find out the subsurface structure of a volcano. Geophysical exploration has several methods commonly used for subsurface interpretation, such as geoelectric, seismic, magnetic, electromagnetic, and gravity methods. This research determined the subsurface structure of Mount Merapi using the gravity method based on secondary data. Secondary data is data obtained from satellites that can be accessed via the page https://topex.ucsd.edu/cgi-bin/get_data.cgi. The gravity method is one of the survey methods in geophysics based on differences in the gravitational field due to differences in the density of rocks that make up the subsurface structure [5]. The physical magnitude measured is the Earth’s gravitational acceleration, which has been corrected to obtain an anomaly of Earth’s gravitational acceleration [6]. From the results of data processing, the differences in rock mass density are obtained then it can be used to determine the subsurface geological structure. The use of gravity methods for geophysical exploration also can be used to find out several things, including knowing subsurface structures as a form of disaster mitigation, determining the fault or fracture of an area, and knowing the geothermal potential of a heat source. Previous research to determine the subsurface structure of Mount Merapi was conducted by Sarkowi (2010). In that study, it was found that the Merapi volcano had a convex magma bag with a depth of 500-6000 meters from MSL. Another study was conducted by Indriana et al. (2018) about the analysis of observational gravity data from 1988-1998-2011 to changes in the value of Mount Merapi gravity. The study found an increase in mass on the surface around the peak of Merapi after the eruption.

According to the previous research findings and the fact that Mount Merapi is an active volcano whose subsurface may change, this research field’s novelty is needed. The consideration of negative impacts caused by the eruption also emerges in this research as disaster mitigation; thus, it requires information on the subsurface structure of Mount Merapi. Besides, the magma chamber’s location can be predicted so that the processes can be identified.

2. Methodology

The method used is a literature study of several references relating to Mount Merapi and processing gravity data. The basis of this gravitation method is Newton’s Law. This law states that two particles’ attraction is directly proportional to each masses and inversely proportional to the square of their distance [7]. Mathematically, the law can be calculated as follows:

$$F = G\frac{m_1 m_2}{r^2} \tag{1}$$

The gravity method depends on measuring variations in the gravitational field caused by horizontal variations in subsurface mass density [8]. Generally, the results of measurements made directly, the gravitational field obtained in the field still contain values that are not derived from subsurface conditions. Therefore, interpretation is needed corrections, consisting of tide correction, drift correction, normal gravitational field correction, free air correction, and field correction [9]. However, if we use secondary data, the obtained is a complete Bouguer anomaly data. The complete Bouguer anomaly itself is the difference between the observed gravity's value and the theoretical gravity defined at the observation [2], [9]. Mathematically the complete Bouguer anomaly can be calculated using a formulation:

$$CBA = (g_0 + FAC - BC + TB) - g_n \tag{2}$$

where CBA is a complete Bouguer anomaly, g_0 is the gravity value of observation (measurement), FAC is free air correction value, BC is Bouguer correction, TC is terrain correction, and g_n is theoretically gravity. Then, the theoretically gravity value can be obtained by using an equation:

$$g_n = 978{,}0218\,[1 + 0{,}0053204(sin^2\varphi) - 0{,}0000058(sin^2\varphi)] \tag{3}$$

Bouguer anomaly in the gravity method is caused by anomalous objects that are both close to the surface and far from the surface of the Earth [2]. Because geophysical surveys aim to study structures closest to the surface, separate regional and residual effects are needed. This residual anomaly itself is different from the Bouguer anomaly, complete with regional anomalies [6]. Usually, the effects of subsurface structures are related to the regional anomaly, and the effects of surface structures close to the surface are related to the residual anomaly [9].

This research used secondary data received from the satellite and can be downloaded through https://topex.ucsd.edu/cgi-bin/get_data.cgi. The data obtained, including the geographic location and the elevation of Mount Merapi. Afterwards, the data are separated into regional and residual Bouguer anomalies by using MagPick software. Before Bouguer anomaly data was processed, first using Surfer software before opening in MagPick and finally separated into regional and residual Bouguer anomalies. Another separation method used is manually, namely by subtracting Bouguer anomaly data complete with regional anomaly data.

After the separation has been carried out, plotting the residual anomaly, both originating from processing with MagPick or manually using Surfer. The data is stored in a storage format that is compatible with other processing software, Grav2dc. This software aims to describe the subsurface structure model of the study area, which are Mount Merapi and rock mass density values used to analyze results. Then, compare the results of local anomaly processing with software and manuals. As an illustration of how this research analyzed the data, below is the data analysis diagram.

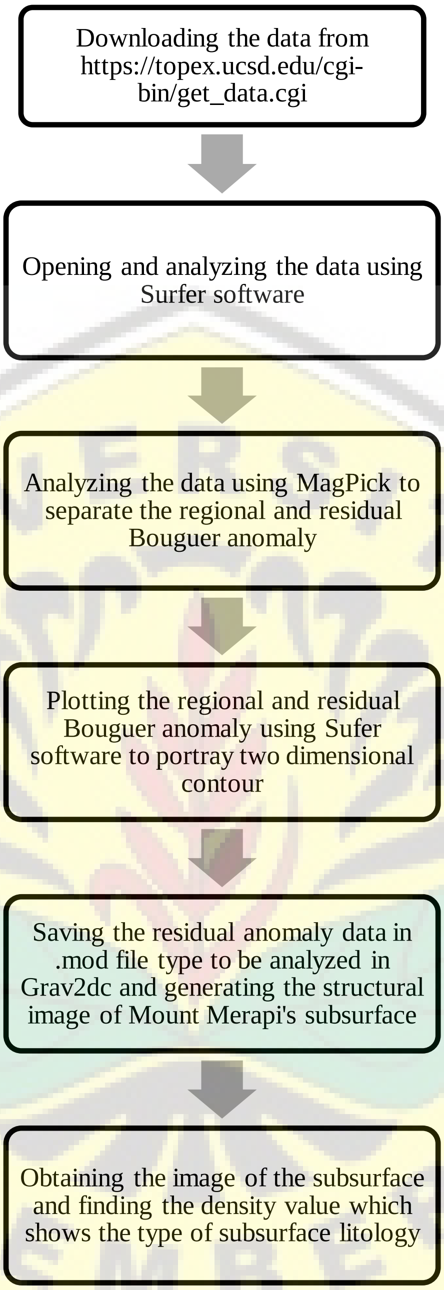

Figure 1. Data analysis diagram

3. Result

Measurements have been carried out in the Mount Merapi area using the gravity method to obtain a complete Anomaly Bouguer (CBA). The complete Bouguer anomaly pattern of the Merapi Mountain region is shown in Figure 2. Figure 3 and Figure 4 show regional and residual Bouguer anomaly pattern that classified by using MagPick software. By using Sufer software, this residual Bouguer anomaly is then slashed to produce an A-B cross-section. The cross-section is then processed using Grav2dc to obtain the value of the density or mass density of rocks that exist beneath the surface of the Earth. The incision results in cross-section A-B with 100 points showed by Figure 5.

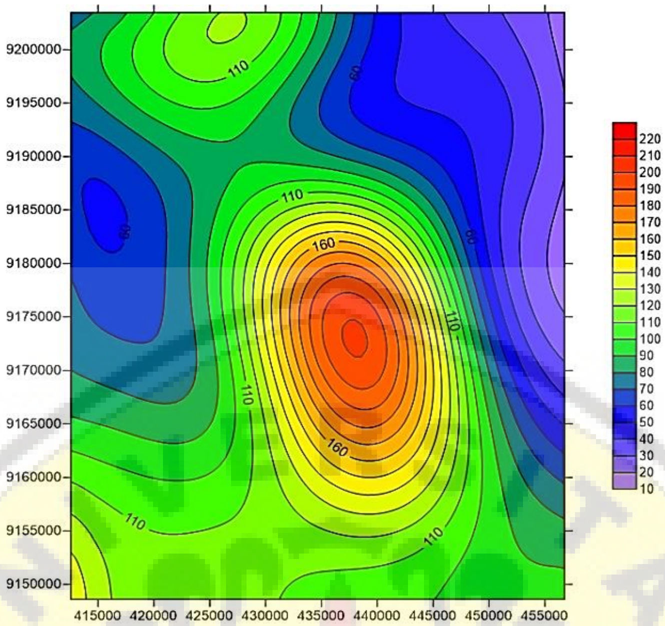

Figure 2. Complete Bouguer anomaly pattern of Mount Merapi Area.

In Figure 2, the complete Bouguer anomaly ranges from 10-220 mGal. This anomaly value is the total anomaly value caused by the influence of rock mass density from the subsurface. The complete Bouguer anomaly responses must be separated regionally and residually to clarify the shape of anomalies near the surface and those far from the earth's surface.

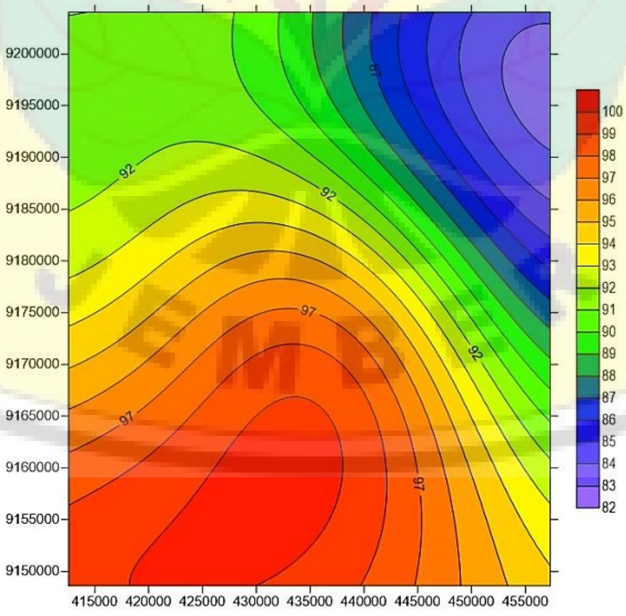

Figure 3. The pattern of regional Bouguer anomaly.

Based on the figure, the regional Bouguer anomaly has a value of 82-100 mGal. This regional anomaly arises because it is influenced by structures deep or far from the subsurface.

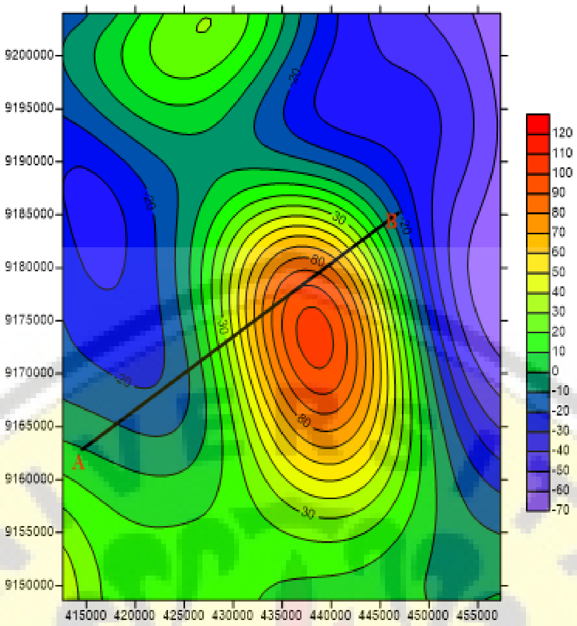

Figure 4. The pattern of the residual anomaly with cross-section A-B.

Figure 4 shows that the anomaly values range from -70-120 mGal. In this study, the interpretation is carried out with geological conditions close to the subsurface. In this residual anomaly, a cross-sectional A-B incision was performed.

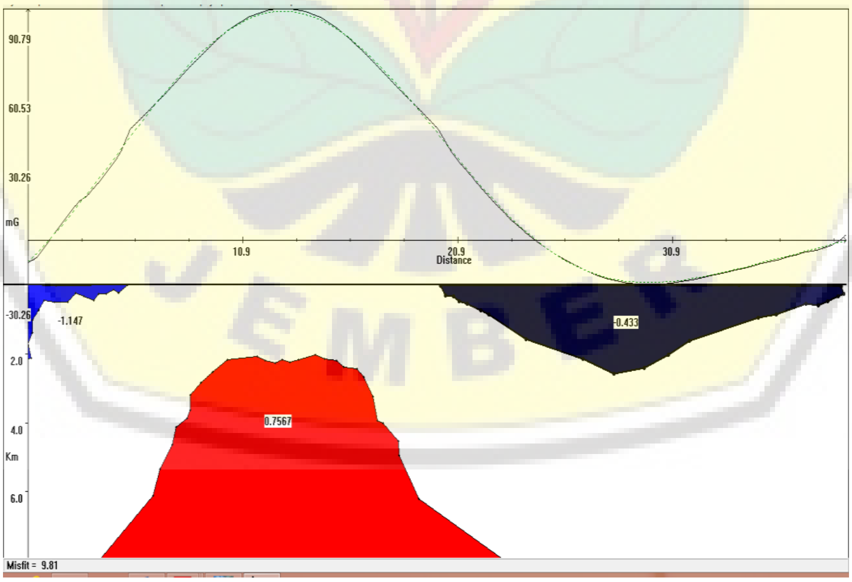

Figure 5. The modeling a cross-section incision A-B.

Based on the A-B, the modeling was carried out using Grav2dc software to produce Figure 5. This modeling is done by making a closed polygon shape and changing it to order to obtain a match between the anomaly curve of the measurement result and the rock susceptibility .

4. Discussion

After the secondary data obtained from the satellite, the data analyzed using Surfer method. The first result showed the complete Bouguer anomaly contour pattern. X-axis and Y-axis indicated the latitude and longitude point of the research location. Those patterns are provided in different colours to indicate the gravity value of the location. In Figure 2, it can be seen the lowest gravity value showed in purple of 10 mGal, and the highest gravity value showed in red of 220 mGal.

After the Sufer analysis has been done, the next step was the gravity value separation of complete Bouguer anomaly pattern into regional and residual gravity value of Bouguer anomaly using MagPick software. To obtain the contour pattern, as can be seen in Figure 3 and Figure 4, the researcher used Surfer software. As the X-axis and Y-axis in Figure 1 promoted the latitude and longitude point of the research's location, Figure 3 described the lowest and highest gravity value by showing different colours; purple and red, to indicate the gravity value of 82 mGal and 100 mGal. While in Figure 4, we obtained the lowest gravity value was -70mGal and 20 mGal as the peak point. In providing the residual Bouguer anomaly pattern, it has been done using Krigging method. The Kriging method was chosen because this method is perfect for problems of spatial structure, anomaly components, and separation of noise [11].

This residual Bouguer anomaly is then slashed to produce an A-B cross-section. In the A-B cross-section showed in Figure 5, the X-axis shows the distance of the track, the Y-axis in the curve area shows the anomaly values observed, and the Z-axis modeling direction shows depth.

The quantitative cross-section is taken based on the results of a qualitative interpretation of the anomaly contour pattern. The A-B cross-section cuts the height and low anomaly with the highest value of about 100 mGal and the lowest value of -30 mGal. Its subsurface depth is 8000 m. The modeling results show that the contrast density varies, namely -1.147, -0.433, and 0.7567. This density contrast is the difference in density between the rock itself and its surroundings.

The white layer shows the dominant constituent rocks of the study area. Based on references, the dominant constituent rocks are basalt-andesite. Basalt-andesite density value is 2.67 g / cm3.

Then another density contrast value is added and subtracted from the reference density value. As a result, the density value for the A-B section is at a density of 1.52 g / cm3 - 3.42 g / cm3. As a consideration, the geological structure of the Mount Merapi area based on a table of rock density ranges, the subsurface lithology might be shown by the following table.

Table 1. Lithologies interpretation table based on the density contrast value.

Contrast density(g/cm^3)	Density (g/cm^3)	Lithology
0	2.67	Basalt-andesite
-1.147	1.52	Pyroclastic
-0.433	2.24	*Pyroclastic*
0.757	3.42	Magma chamber

Based on the table, it shows the dominant constituent layers form basalt-andesite. Then at a depth of fewer than 2000 meters is a pyroclastic rock which is a rock formed by volcanic eruptions that were deposited. Then at a deeper depth, it is estimated that it is a bag of magma.

5. Conclusion

The study about the interpretation of the structure under Mount Merapi by using secondary data using the value of the Earth has been done. Processing uses Surfer assistance to determine the complete Bouguer anomaly pattern, regional anomaly pattern, and residual anomaly pattern. The complete Bouguer anomaly pattern has a gravity value of 10 mGal - 220 mGal, a regional anomaly has a gravity value of 82 mGal - 100 mGal, and the residual anomaly pattern has a gravity value of -70 mGal - 120 mGal. From the residual anomalous cross-section pattern, an attachment is made to model the two-dimensional subsurface structure of Mount Merapi using Grav2dc software. A local anomaly produced the first incision with MagPick based on the results of the incision obtained by interpretation of the subsurface lithology of Mount Merapi including basalt-andesite, pyroclastic rocks, and magma chamber.

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