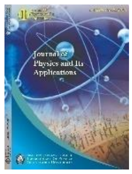
Journal of Physics and Its Applications

Journal homepage : https://ejournal2.undip.ac.id/index.php/jpa/index



Applications of Gravity Method Based on Satellite Image Anomaly Data to Identify Subsurface Structures

Namyra Aisha Althafunnisa[1], Sheren Aurellya Herbianto[1], and Agus Setyawan[2,*]

[1]*Master of Physics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia*
[2]*Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia*

* *Corresponding author: agussetyawan@fisika.fsm.undip.ac.id*

ARTICLE INFO

Article history:
Received: 27 December 2023
Accepted: 19 May 2024
Available online: 31 May 2024

Keywords:
Gravity Methods
Subsurface Structure
Satellite Images
Bouguer Anomaly
Rock Density Variation

ABSTRACT

We have reviewed several research related to the estimation of subsurface structure on several area in Indonesia using gravity method based on satellite image. There are located in Semarang City, Mount Tandikat, Mount Muria, Majene Earthquake Affected Area, and Mount Merapi-Merbabu. The aim of this literature study is to determine the accuracy of satellite gravity data to identify and model subsurface structures by testing them in several cases. Data processing was carried out starting from the free air anomaly and then field correction was carried out to obtain the Bouguer anomaly. Moreover, different advanced processing is carried out, such as gradient analysis, 2D and 3D modeling. The software used includes GRAV2DC, Gravblox, Bloxer, and Grav3D.The results show variations in rock density and subsurface structure at each location. Subsurface modeling includes rock types, faults and basins that can help understand local geology. The study also shows estimates of the thickness of the sediment layers at several research locations. The research results show variations in rock density in various locations (granite, sandstone, andesite, mudstone) with different density values (between 1 g/cm^3 to 2.9 g/cm^3). Generally, gravity data from satellite images can provide subsurface information such as lithology, geological potential, the presence of hydrothermal pathways and structures. Regarding the type of fault, it is necessary to carry out geological observations in the field and cannot just rely on the results of gravity modeling. Furthermore, the results of gravity mapping will play an important role in disaster risk management and understanding geodynamics in the area studied.

1. Introduction

Indonesia, as a country located on the Pacific Ring of Fire, is a region that often experiences significant geological activities, such as earthquakes, volcanic eruptions, and other geological phenomena. Research on the identification of subsurface structures has become a major focus in geological understanding and disaster risk mitigation. One method that is increasing attention is gravity method which is taken from satellite image. This method utilizes changes in the strength of the gravity field at the Earth's surface to identify variations in the density of the underlying rocks. The success of several previous studies, such as Mount Merapi and Mount Merbabu-Merapi has shown the potential of this method in mapping and understanding complex geological formations in volcanically active areas [1] [2].

This method not only provides a structural overview, but also helps in identifying potential geological hazards, such as volcanic eruptions or plate shifts. Bener Meriah district has utilized to understand the natural resource potential and geological risks in the area [3]. In other places such as Sumber Manjing Wetan Village and Druju Village in South Malang has provided a deep understanding of underground formations that affect infrastructure and water resources [4].

Along with the importance of the success studies, the gravity method has applied it in different contexts is increasing. The eruption of Mount Semeru in 2022, for example, triggered an urgent need to understand the impact of the eruption and potential future threats [5]. Meanwhile, Mount Ijen Banyuwangi becomes crucial in the context of environmental conservation and mineral resource utilization [6].

Two-dimensional modelling subsurface structure estimation at Mount Kelud [7], gravity methods have been used to get an in-depth picture of the subsurface structure of Mount Kelud, an area with high volcanic activity. In the Slamet volcano area, a similar approach was used to identify potential geothermal reservoirs, which has significant implications for renewable energy [8].

Volcanological Survey of Indonesia has studies gravity survey in Central Java demonstrate the relevance of this method in the context of regional geology, allowing researchers to gain an in-depth understanding of subsurface structures over large areas [9]. Meanwhile, on the Bentarsari Basin of Brebes shows the importance of integrating data from various satellite sources to get a more comprehensive picture [10].

On a more specific scale, studies such as Gradient analysis of gravity and magnetic data beneath Gedongsongo geothermal manifestations. The results shows that geothermal manifestations in Gedongsongo area has well corelated with fault [11]. Moreover, based from mathematical analysis of Bouguer correction demonstrate the effectiveness of this method in the context of geothermal and detailed understanding of subsurface structures [12]. Furthermore, with this research Complete Bouguer Anomaly Mapping, this study demonstrates the direct application of the gravity method in the mapping and qualitative analysis of rocks in the Paman Calan geothermal area [13].

Overall, the Gravity method based on satellite image anomaly data has proven to be an effective tool in geological research. Its success in several studies has emphasized its urgency and relevance in understanding, mitigating and responding to diverse geological challenges in various regions. Therefore, follow-up research with similar approaches in different locations is expected to provide broader and deeper insights for community sustainability and security.

The method used in this literature study is the gravity method based on satellite image anomalies. This method allows identification and modeling of subsurface structure and mass distribution in various locations, including Semarang City, Mount Tandikat, Muria Peninsula, Majene earthquake-affected area, and Mount Merapi-Merbabu.

Semarang City, as the capital of Central Java Province, is one of the cities with significant geothermal potential. To effectively utilize geothermal resources, an in-depth understanding of the subsurface structure and density distribution of rocks is required. This study aims to contribute to the exploration of geothermal resources in the region [14].

Mount Tandikat, located in West Sumatra, is also a crucial research site. Geothermal energy is one of the potential renewable energy sources, but to utilize it effectively, a deep understanding of the subsurface structure is required. This research aims to identify rock structures and faults on Mount Tandikat, which can provide important information in the development of geothermal potential in the area [15].

Mount Muria, located in Central Java, has a deep need for an understanding of subsurface structures. The region has a rich geological history and potential for natural disasters such as earthquakes. This research uses gravity methods to model the subsurface structure and identify variations in rock density in the study area. This will provide a better understanding of the geological evolution of the Muria Mountain and potential disasters that may occur [16] [17].

The Majene area in West Sulawesi is also a focus of research, especially in disaster mitigation efforts. An understanding of the subsurface structures around this region is essential. Power spectral analysis of gravity anomaly data is used to estimate sediment depth and identify subsurface structures. The results of this study will provide valuable information for disaster mitigation efforts and regional development in the region [18].

Finally, this study also covers Mount Merapi and Mount Merbabu. Both of these mountains are active volcanoes, and an understanding of the structure and characteristics of the subsurface magma chamber is crucial for future volcanic disaster risk mitigation. This research can also contribute to the understanding of volcanic activity in this region [19].

2. Methods

The underlying theory of gravity surveys is Newton's law of attraction between two point masses, where the magnitude of the force between two point masses m_1 and m_2 separated by a distance is

$$\vec{F}(\vec{r}) = -G\,\frac{m_1 m_2}{r^2}\,\hat{r} \tag{1}$$

where F is the force (Newton), $\hat{r}$ is the distance between the two bodies (meter), m_1 and m_2 are the masses of each body (kg), and G is the universal gravitational constant (6.67 x 10^{-11} Nm^2/kg^2). Furthermore, the force per unit mass of particle m_1 that has a distance from m_2 is called the gravitational field of particle m_1, which can be expressed as:

$$\vec{E}(\vec{r}) = \frac{\vec{F}(\vec{r})}{m_2} = -G\,\frac{m_1}{r^2}\,\hat{r} \tag{2}$$

Since the gravitational field is conservative, it can be written as the gradient of a scalar potential function *U(F)* so that equation (2) can be written as:

$$\vec{E}(\vec{r}) = -\nabla\,\vec{U}(\vec{r}) \tag{3}$$

with $\vec{U}(\vec{r}) = -G\,\frac{m_1}{r^2}$ is the gravitational potential of the mass m_1.

The research method applied is to conduct a literature review and analysis of previous studies that have been carried out in various locations, including: Semarang City area, Central Java, Indonesia [14]; Mount Tandikat, West Sumatra, Indonesia [15]; Mount Muria, Central Java, Indonesia [16]; Majene Area, West Sulawesi, Indonesia [18]; lastly, Mount Merapi and Mount Merbabu, Central Java, Indonesia [19].

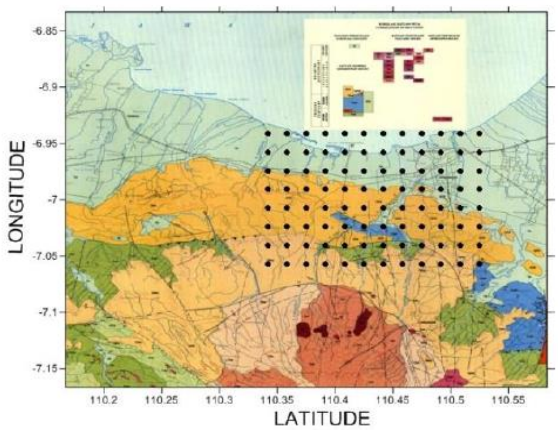


Fig. 1: Research area in Semarang City area, Central Java, Indonesia [14]

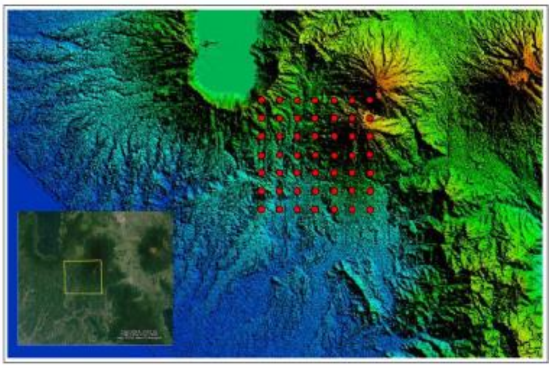


Fig. 2: Research area in Mount Tandikat, West Sumatra, Indonesia [15]

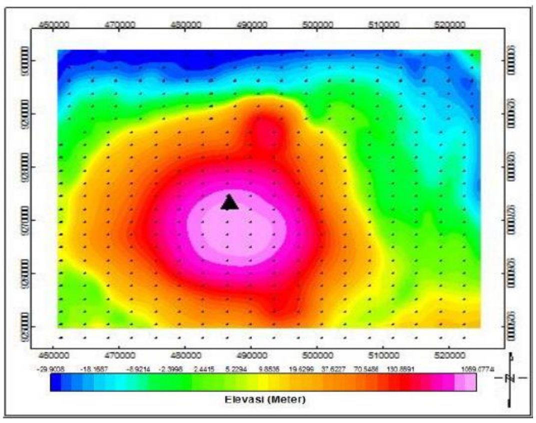


Fig. 3: Research area in Mount Muria, Central Java, Indonesia [16]

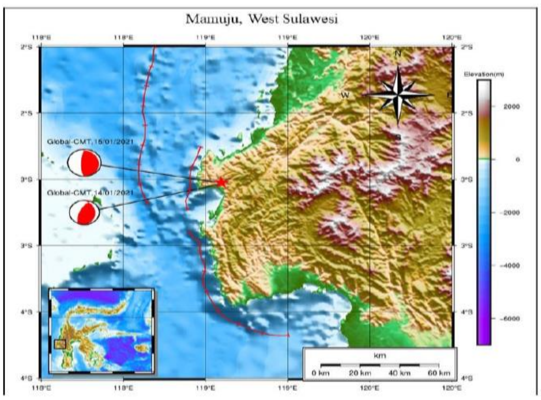


Fig. 4: Research area in Majene, West Sulawesi, Indonesia [18]

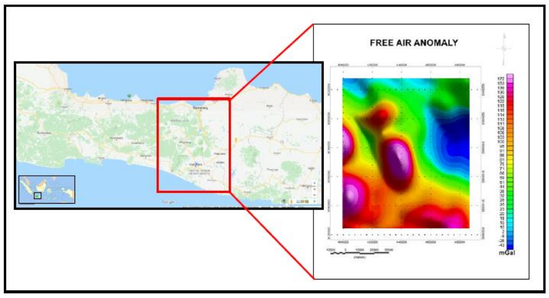


Fig. 5: Research area in Mount Merapi and Mount Merbabu, Central Java, Indonesia [19]

The research methods used in the previous study were a key step in the estimation of subsurface structures at various locations in Indonesia. In the data processing process of each location, not all are the same, but most include a series of steps focused on analyzing gravity anomalies using satellite imagery, as well as 2D and 3D modeling using several specialized geophysical software tools. The following is a description of the research methods used:

2.1. Gravity Data Collection

Gravity data was obtained from satellite images covering the study area, including Semarang City, Mount Tandikat, Muria Peninsula, Majene earthquake-affected area, and Mount Merapi-Merbabu. This data includes gravity anomaly values at every point on the earth's surface [6].

2.2. Bouguer Correction and Topographic Correction

The gravity data obtained above needs to undergo Bouguer correction and topography correction. Bouguer correction is required to remove the gravitational effects of materials above the measurement point, including topography. This aims to obtain a complete Bouguer anomaly [20].

2.3. Power Spectral Analysis

The obtained gravity anomaly data were analyzed using power spectral analysis. The ABL (complete Bouguer anomaly) data is converted from distance domain to wave number domain using Fourier transform. Power spectral analysis provides insight into the distribution of rock mass in the subsurface and helps in identifying subsurface structures [20].

2.4. 2D and 3D Modeling

2D and 3D modeling is performed using specialized software, such as GRAV2DC, Grablox, Bloxer, and Grav3D. This modeling aims to identify and model subsurface structures. The modeling results include rock types, faults, and basins in each of the research locations [20].

2.5. Regional and Residual Anomaly Analysis

During the analysis, regional and residual anomaly analysis was also conducted. This aims to identify deeper and shallower sources of anomalies. This analysis provides an estimate of the regional depth and residual anomalies associated with the subsurface structure [21].

2.6. Interpretation of Results
The results of the modeling and analysis are used to interpret the subsurface structures at each of the study sites. This includes rock types, faults and depressions that aid the understanding of the local geology [22].

3. Results and Discussion

From the five studies we have reviewed, the application of gravity methods based on satellite anomaly data to identify subsurface structures makes a significant contribution to the understanding of geological areas Semarang City [14], Mount Tandikat [15], Mount Muria [16], Majene Earthquake Affected Area [18], and Mount Merapi-Merbabu [19].

In the first study, gravity anomaly data measured by satellites must go through processing before it can be interpreted to estimate subsurface structures. Data processing resulted in Bouguer anomaly values that showed a diverse distribution, with a maximum value of 19 mGal and a minimum value of -4 mGal. The average density of the surface rocks is 2.67 g/cm^3.

Based on the Bouguer anomaly contour map, rock contacts between low and high-density rocks were identified. The first rock contact layer has a density contrast of 1 g/cm^3 with a rock density contrast of 2.8 g/cm^3. The next rock contact has a density contrast of 0.7 g/cm^3 with a density contrast rock of 2.76 g/cm^3. The contact layer is supported by a solid base layer with a density contrast of up to 2.9 g/cm^3.

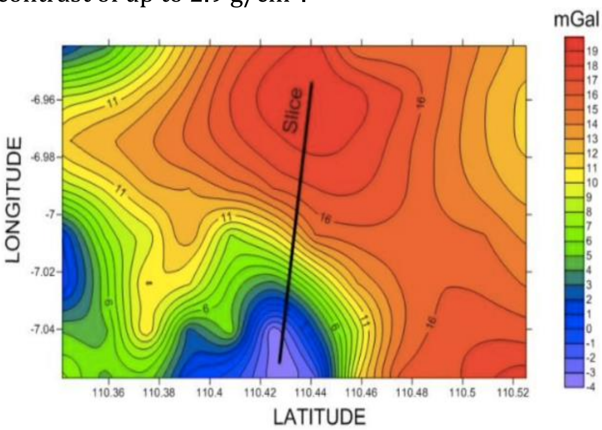


Fig. 6: Complete-Bouguer Anomaly Map in Semarang City [14]

The results of this study provide an in-depth understanding of the subsurface structure in the study area. 2D modeling with density contrast is able to identify rock layers and contacts between rocks with different densities. However, there are limitations to the measurement data, in that the gravity anomaly data from the Topex/Poseidon satellites must be processed before it can be interpreted. This includes the uncertainty of translating anomaly values into accurate subsurface structures. There are also limitations in the spatial resolution of the data that can affect modeling accuracy, especially in areas with high density variations [14].

In the Second Study, the Bouguer anomaly contour map shows three zones with different value ranges. Zone I, located at the top to the foot of Mount Tandikat and Maninjau Caldera with a range of -124.4 mGal to -17.3 mGal. Zone II, in the range of -13.9 mGal to -0.5 mGal, is dominated in the southern part of the study area. Zone III, located in the landslide area of Mount Tandikat with a range of 2.1 mGal to 29.1 mGal.

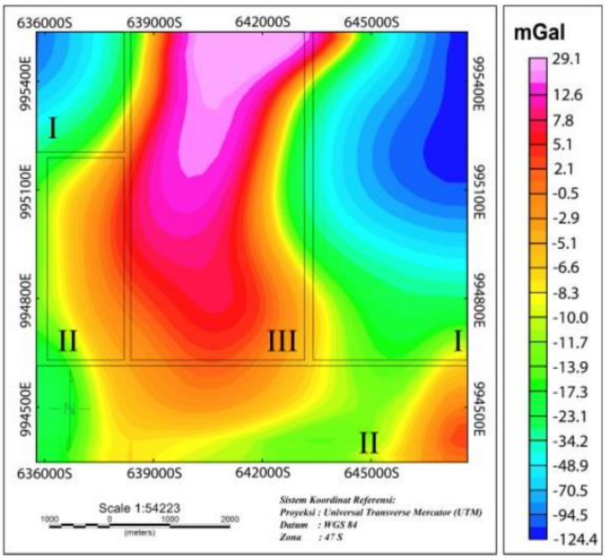


Fig. 7: Complete-Bouguer Anomaly Map in Mount Tandikat [15]

Negative Bouguer values occur because they involve a reduction in the attraction of mountain masses, especially in larger mountainous areas. CBA filtering produces regional and residual anomaly maps. The regional anomalies are in the range of -199.0 to 30.3 mGal, while the residual anomalies are in the range of -28.7 mGal to 21.8 mGal. 2D interpretation using slicing on the residual anomaly map provides an overview of the subsurface structure. The interpretation results show rock layers with varying thicknesses, rock densities between 1.93 g/cm^3 to 2.9 g/cm^3, and the dominance of andesite rocks. This study presents a comprehensive identification of subsurface structures in the study area. Starting from Bouguer anomaly analysis, CBA filtering, 2D interpretation, to derivative analysis, all stages are carried out thoroughly. Although the 2D interpretation results provide a detailed picture of the subsurface structure, there is an error rate of 1.76%. This can be caused by variations in rock type and thickness which are difficult to predict precisely. In addition, derivative analysis requires careful interpretation, and the results may be affected by certain assumptions used in the analysis process [15].

In the third study, the Bouguer anomaly contours show three rock density zones: low, medium, and high density. The Bouguer anomaly values range from 169.5 mGal to 197.7 mGal.

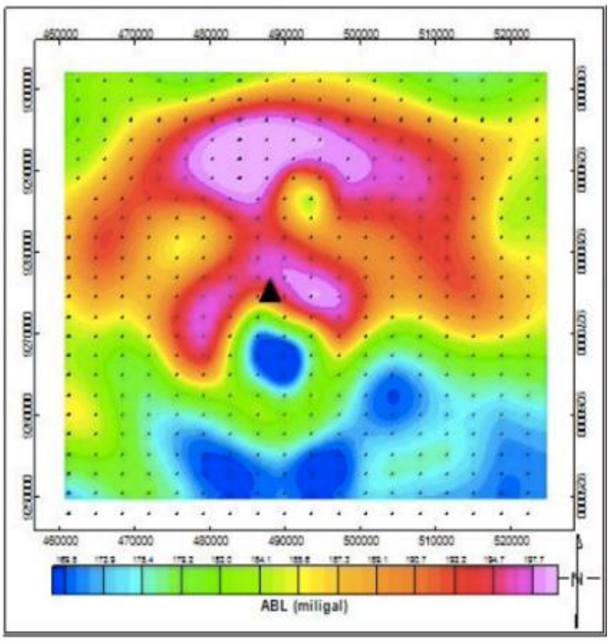


Fig. 8: Complete-Bouguer Anomaly Map in Mount Muria [16]

Low anomalies are interpreted as areas with low rock density, possibly caused by alluvial sedimentary deposits or tectonic basins. Medium and high anomalies are associated with the slopes of Mount Muria and older volcanic rocks. Subsurface structural modeling using five incision passes revealed rock layers with significant density contrasts. The average density of the surface rocks is 2.67 g/cm^3. 2D modeling shows several rock layers with different densities and thicknesses. The modeling results table presents information on rock layers, depth, thickness, density contrast, and rock type. The modeling results show rock contacts that can be indicated as faults.

There are several contact layers, with low density (1 g/cm^3) meeting high density (2.8 g/cm^3). The modeling indicates the presence of complex structures, including a dense base layer with a density of 2.9 g/cm^3. This research integrates several methods that can provide a more comprehensive understanding of the geological structure in the study area, but has the limitation of using Bouguer anomaly data obtained from a single source, namely from the website http://bgi.omp.obs-mip.fr. This limitation in data sources can affect the validity and representativeness of the research results. The use of data from a single source can also increase the risk of bias or uncertainty [16].

In the fourth study, this research focused on analyzing the Bouguer anomaly and estimating the subsurface structure in the Majene region. After processing the free air anomaly data and calculating the average density, Bouguer anomaly values ranging from -50 to 110 mGal were obtained. There is an anomaly distribution pattern, with high values centered in the southern part and low values in the northern edge, in accordance with the negative correlation between Bouguer anomaly and topographic elevation. Furthermore, power spectrum analysis on the Bouguer anomaly map reveals information about the thermal structure of the mantle and variations in crustal thickness.

The analysis was performed separately for the East-West and North-South paths, yielding regional and residual anomaly depth estimates. The depth variations are related to various geological sources, which are then interpreted as the thickness of the sedimentary layers.

Sediment thickness profiles were generated for both directions, showing the complexity of the underlying structure is more complicated than before. The results of the power spectrum analysis were validated by comparing them with previous studies on subsurface structures in the Majene region. Three-dimensional modeling shows the dominance of claystone with variations in density, ranging from 1.6 g/cm^3 to 2.4 g/cm^3.

The Map of Majene Bouguer Anomaly that has been sliced by nine lines for the East-West and North-South direction to obtain the profile of anomalies. Slicing in the horizontal direction (East-West) will interpret the North-South depth profile, while Slicing in the vertical direction (North-South) will interpret the anomalous profile of the East-West depth (Fig 9).

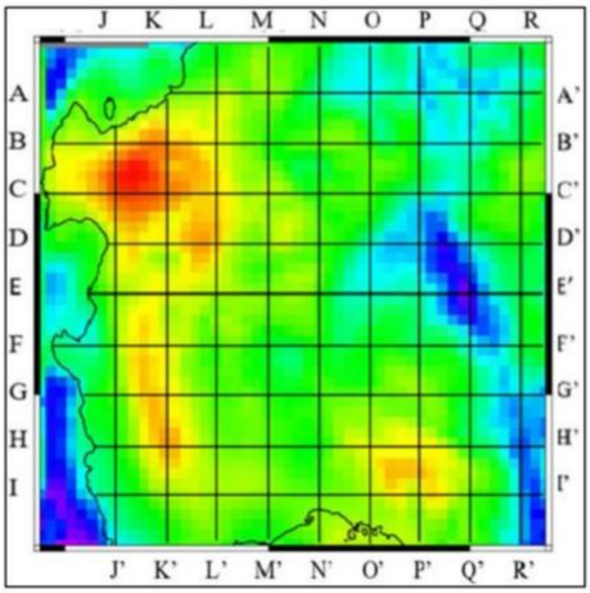


Fig. 9: Complete-Bouguer Anomaly Map in Majene Region [18].

The average depths of deep and shallow discontinuities were calculated for the East-West and North-South directions, providing comprehensive information on the subsurface structure. Correlation with the geological map of the Majene region supports the findings, showing that the region is dominated by marine sedimentary rocks. This study provides results consistent with the theory of earthquake amplification factors related to the thickness of sedimentary layers. However, this study has limitations due to the modeling and inversion methods used. The use of power spectra for sediment thickness estimation can have a certain degree of uncertainty, affecting the accuracy of the results obtained [18].

In the fifth study, based on the Bouguer anomaly contour map and the results of subsurface layer structure modeling in the southern region of the study, especially around Mount Merapi and Mount Merbabu's magma chamber shows high anomalies, reaching 115-175 mGal, indicating high density in the subsurface. The free-air anomaly values decrease towards the eastern and southern parts of the research area. The elevated anomalies observed around the Merapi-Merbabu volcanoes suggest increased subsurface density in those areas.

The Bouguer anomaly map was further adjusted to create a Complete Bouguer Anomaly (CBA), with gravity values ranging from -300 to 300 mGal. The elevated anomaly is situated around Mount Merapi and Merbabu, while a lower anomaly is observed in the eastern section of the study area. The presence of a high anomaly correlates with increased density in that particular region. These findings align with previous studies indicating that the Mount Merapi-Merbabu complex exhibits higher density compared to surrounding rock formations.

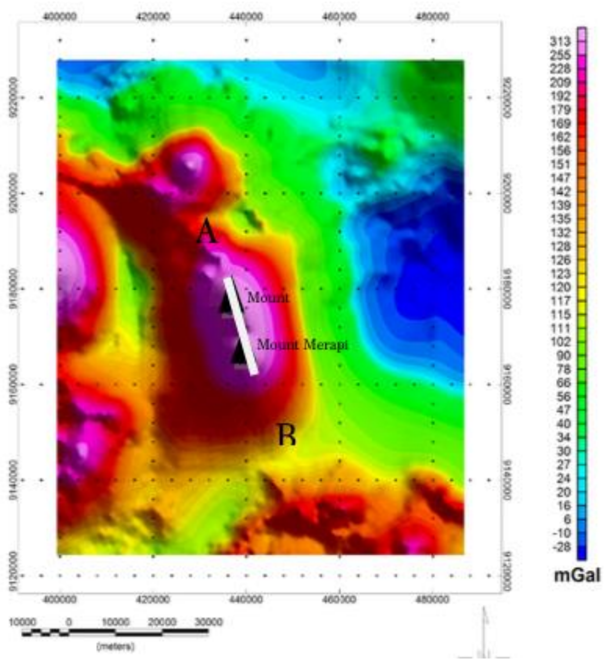


Fig. 10: Complete-Bouguer Anomaly Map in Mount Merapi and Mount Merbabu [19]. The high anomaly indicates high density in that area than the other rocks around Mt. Merapi and Mt. Merbabu. Profile A-B was marked by white line in the map.

Secondly, 2-D gravity modeling was performed to separate the anomaly into a series of spatial components related to density "depth slices". Five subsurface layers under Mount Merapi and Merbabu were identified, including pyroclastic rocks, magma chambers and bedrock with varying density values [19]. Third, the pyroclastic rock layer has a density of about 2.15 g/cm^3 at a depth of 0-500 m, while the magma layer shows differences between Mount Merapi and Merbabu, with densities ranging from 2.6-2.75 g/cm^3. The bottom layer has a density of about 2.8 g/cm^3 at a depth of 5-8 km, while the top layer reaches 3.0 g/cm^3 [19]. Fourth, there are two magma chambers under Mount Merapi, with densities of about 2.70 g/cm^3 and 2.75 g/cm^3. Mount Merbabu has a magma chamber with a higher density, reaching 2.75 g/cm^3 at a depth of 4.5 km [19]. Fifth, the difference in magma chamber density and depth may explain why Mount Merapi is more volcanically active than Mount Merbabu [19].

This study provides deep insight into the structure of the subsurface layers in the Majene region, having important implications for the understanding of seismic risk and construction planning in the area. However, limited direct validation through independent geological methods or comparison with direct field measurements is required to improve the accuracy of the data in this study [19].

Overall, these five studies provide important contributions to the understanding of subsurface structures using gravity methods and satellite anomaly data. Although each has advantages and disadvantages, combining the findings from these five studies can provide a more comprehensive understanding of the geological characteristics of the respective study areas.

4. Conclusions

The conclusion of this research is that the gravity method based on satellite image anomaly data, especially analysis of gravity data with Bouguer correction, power spectral analysis, 3D modeling using Grav3D software, and regional and residual anomaly analysis, can be used to identify and model subsurface structure and mass distribution in various areas, including Semarang City, Mount Tandikat, Mount Muria, Majene earthquake affected area, Mount Merapi, and Mount Merbabu.

Acknowledgments

This research was supported by the Institute for Research and Service and the Master of Physics Education at Ahmad Dahlan University.

References

[1] U. Chasanah, S. D. A. Febriani, and E. Minarto, "Estimating the Subsurface Structure of Mount Merapi Based on Analysis of Satellite Image Gravity Field Anomaly Data," J. Fis. Flux J. Ilm. Fis. FMIPA Univ. Lambung Mangkurat, 18 (1), p. 25, (2021).

[2] M. Sarkowi, "Interpretation of Subsurface Structure of Mount Merbabu - Merapi Area Based on 3D Modeling of Bouguer Anomaly," Berk. Fis., 13(2), pp. 11–18, (2010).

[3] M. Kamal, Marwan, and Muhibbuddin, "Interpretation of Geological Structure Distribution Based on Satellite Image Gravity Field Anomalies in Bener Meriah Regency," Earth Engineering Student Scientific, 1(1), pp. 9–12, (2017).

[4] W. Ramadhani, Sunaryo, and Wasis, "Identification of Subsurface Structure Using Gravity Method in Sumbermanjingwetan Village and Druju Village - South Malang," J. Fis. FMIPA Univ. Brawijaya, 11, pp. 1–6, (2014).

[5] F. K. Ayu Anggraeni, "Identification of the

Subsurface Structure of Mount Semeru After Eruption in 2022," Journal of Physical Science and Innovation., 7(1), pp. 69–77, (2023).
[6] A. N. Hamidy et al., "Analysis of the Subsurface Structure of Mount Ijen Banyuwangi," Journal of Physics Learning, 11(3), p. 93, (2022).
[7] M. Rahman, Sunaryo, and A. Susilo, "Estimation of 2½-Dimensional Subsurface Structure in Kelud Volcano Area Based on Gravity Survey," Nat. B, 2(3), pp. 221–228, (2014).
[8] A. Reswara and P. A. Sehah, "Estimation of Geothermal Reservoir Layer in Slamet Volcano Area by Utilizing Satellite Image Gravity Field Anomaly Data," Berk. Fis., 17(2), pp. 45–54, (2014).
[9] I. Yokoyama, I. Surjo, and B. Nazhar, "Survei Vulkanologi Indonesia, bag. 4, Survei Gravitasi di Jawa Tengah," Bull. Earthq. Res. Inst., 48, pp. 303–315, (1970).
[10] F. A. dan S. Kurniawan, "Utilization of GEOSAT and ERS-1 Satellite Gravity Anomaly Data to Model the Geological Structure of the Bentarsari Brebes Basin," Indones. J. Appl. Phys., 2(2), p. 188, (2012).
[11] A. Setyawan, H. Yudianto, J. Nishijima, and S. Hakim, "Horizontal Gradient Analysis for Gravity and Magnetic Data Beneath Gedongsongo Geothermal Manifestations , Ungaran , Indonesia," World Geotherm. Congr. 2015, 4, pp. 1–6, (2015).
[12] A. D. Maulana and D. A. Prasetyo, "Mathematical Analysis on Bouguer Correction and Field Correction of Topex Satellite Gravity Data and Application in Geohazard Case Study of Palu Koro Fault, Central Sulawesi," J. Geosaintek, 5(3), p. 91, (2019).
[13] F. Jusmi, "Complete Bouguer Anomaly Mapping and Topographic and Rock Bouguer Density Determination of Pamancalan Geothermal Area," J. Din., 9(1), pp. 1–9, (2018).
[14] P. Nugraha, Supriyadi, and I. Yulianti, "Estimation of Semarang City's Subsurface Structure Based on Satellite Image Gravity Anomaly Data," Unnes Phys. J., 5(2), pp. 37–41, (2016).
[15] W. Trimulyati and A. Putra, "Identification of Subsurface Structure of Mount Tandikat Using Gravity Method Based on Satellite Data," J. Fis. Unand, 11(3), pp. 366–372, (2022).
[16] H. A. N. A. Anisa, R. D. Indriyana, and M. Irham, "Application of Gravity Method with Satellite Data for Identification of Subsurface Structure (Muria Peninsula Case Study)," Youngster Phys. J., 10(2), pp. 244–245, (2018).
[17] P. Astjario and D. Kusnida, "Interpretation of Geological Structure of Muria Peninsula from Satellite Image Data," J. Geol. Kelaut., 5(2), pp. 63–71, (2016).
[18] B. G. Dewanto, R. Margiono, Y. A. Segoro, E. Pramesthi, and A. K. Maimuna, "The importance of gravity data for estimating and identifying the sediment thickness of subsurface structure around Majene Sulawesi Barat," AIP Conf. Proc., 2654(050002), pp. 1–12, (2023).
[19] P. D. Maghfira and S. Windhi Niasari, "Gravity satellite data analysis for subsurface modelling in Mount Merapi-Merbabu, Java, Indonesia," E3S Web Conf., 76(03003), pp. 1–3, (2019).
[20] F. Indrarini Wulandari and A. Setiawan, "3D Subsurface Structure Modeling of Purwokerto and Its Surroundings Based on Complete Bouguer Gravity Anomaly Data," J. Fis. Indones., 19(57), pp. 6–12, (2017).
[21] J. Purnomo, S. Koesuma, and M. Yunianto, "Regional-Residual Anomaly Separation in Gravity Method Using Moving Average, Polynomial and Inversion Methods," Indones. J. Appl. Phys., 3(01), p. 10, (2013).
[22] I. Setiadi and A. Diyanti, "Interpretation of Subsurface Geological Structure of Leuwidamar Area Based on Spectral Analysis of Heavy Force Data," J. Geol. dan Sumberd. Miner., 15(4), pp. 205–214, (2014).