The complete bouguer anomaly changes in 2019 after explosive eruption of merapi in 2010

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Abstract: Merapi is the most active volcano in Central Java and even in Indonesia. Previous research in 1988,1998,2011 by using the gravity method shows an increasing amount of magmas, which are observed from changes in the dimensions of the magma chamber. The aim of this research is to observed the gravity changes nearby summit area after big eruption in 2010. In this research the summit area was close because of the activity of Merapi. The results of further studies in 2019 showed a large anomaly increase of 2 to 5 mGal in the southeast to the southwest. Gravity data in the peak area has not yet been acquired due to the high activity of Merapi. The subsurface interpretation related to changes in the dimensions of the magma reservoir cannot be done, but it can be expected increasing of mass at the southeast of Merapi towards the peak. The increasing amount of mass cause Merapi eruption in 2020.

1. Introduction
Data on the number of volcanoes in Indonesia collected by the Center for Volcanology and Geological Disaster Mitigation (PVMBG) shows that Indonesia has 127 active volcanoes. The range of volcanoes is spread in the path of the volcanoes which runs along 7000 km. A large number of volcanoes that are still active requires ongoing supervision. It is estimated that there are more than 4 million inhabitants who inhabit the area around volcanoes with high volcanic activity. Of the 127 active volcanoes, there are 69 volcanoes that are monitored continuously. Volcanoes that are monitored continuously consist of 47 volcanoes with normal status and 22 volcanoes with alert status. Of the 22 alert volcanoes, there were 8 volcanoes that have erupted. Volcanoes that have erupted/erupted are Anak Krakatau, Ibu Volcano, Dukono Volcano, Semeru Volcano, Tangkuban Perahu Volcano and Merapi Volcano [1].

The existence of volcanoes in Indonesia has become a part of people's lives. When it is calm, The volcano is a pleasant place, but when it is active it is often considered disturbing. Actually, volcanoes never disturb anything around them, but volcanoes have their own rhythms of life that are less understood by humans. Volcanoes are part of the dynamics of the earth system that are interrelated and will always balance themselves after an imbalance occurs. The equilibrium state that must be achieved includes energy balance and structural balance. The release of energy through eruption is one form of balancing the energy that is in/below the surface to that of the surface. Because the amount of energy released in the balancing process is large, humans must be careful, although the results of that process will generally provide great benefits for humans in the future. Old active volcanoes do not show their activity will be very dangerous if an eruption occurs. Large energy accumulates over time. Mount Sinabung is one of the volcanoes that takes a long break and then erupts. The eruption that happened was devastating and hasn't stopped until now. This shows that the energy stored so far is very large.
The In Java, there are 19 active volcanoes. In Central Java, there are Merapi Volcano (2,930 m) and Slamet Volcano (3,428 m). In West Java, there is Tangkuban Perahu Volcano (2,084 m) and Ciremai Volcano (3,078 m). East Java has the highest number of active volcanoes compared to other provinces in Java. Volcanoes in East Java consist of Lamongan Volcano (1,651 m), Straight Volcano (539 m), Arjuno Volcano (3,339 m), Welirang Volcano (3,156 m), Baluran Volcano (1,247 m), Raung Volcano (3,332 m), Kawi Volcano (2,551 m), Butak Volcano (2,868 m), Argopuro Volcano (3,088 m), Penanggungan Volcano (1,653 m), Ijen Volcano (2,779 m), Kelud Volcano (1,731 m), Semeru Volcano (3,676 m) and Bromo Volcano (2,329 m) [1]. Because the number of active volcanoes in Java is large, it is necessary to understand the environment of volcanoes in the communities around the volcano. Environmental monitoring of volcanic areas is part of the mitigation of volcanic disasters. The introduction of the volcano disaster should have been introduced early on to the community. Indonesia, which is geographically an area formed over of 2 plates, is certainly very vulnerable to the dangers of volcanic and tectonic disasters [14].

To support mitigation efforts, it is necessary to monitor volcanic activity. Volcanic activity monitoring can be done visually and use physical parameter measurements. Observation of physical parameters is done by using equipment such as gravity meter, magnetometer, seismometer, GPS deformation, biochemical measurements, temperature sensors, CO sensors, and most recently using unmanned aircraft (drones) to observe changes in crater conditions over time. One of the volcanoes on Java whose activities are very high is Merapi. Merapi eruptions occur repeatedly every 2 years, 4th, 10 years, 20 years and even 100 years. The high level of frequency of eruptions makes people to better understand the volcanic activity. Human activities carried out around the active volcano area must adjust the volcano. Various aspects of activities such as environmental, economic, social, and educational activities should be adjusted to volcanic activity. So that in the event of a disaster resulting in environmental damage, economic and social losses can be reduced [2;12;15;20].

In October 2010, there was a Merapi eruption with a VEI 4 scale. The VEI 4 scale was a scale marked by an eruption column as high as 6 km from the air. Generally Merapi eruption on a scale of VEI 1 and 2. If VEI is higher, the level of damage will be greater, causing greater material and non-material losses. As a result of the 2010 eruption, there were 206 fatalities and 384,136 refugees from Central Java and DIY. As many as 486 injured were treated in several hospitals such as Klaten Regional Hospital, City and Magelang District Hospital, Boyolali District Hospital, and Sleman District Hospital, while 500 victims of depression due to the disaster were treated at Magelang and Klaten Hospital. Merapi eruption always affects the people's economy such as the death of livestock (1548 head of cattle and sheep), damage to agricultural land and plantations, destruction of villages and people's homes, the cessation of tourism services businesses and their supporters. Another economic impact due to the Merapi eruption in 2010 was that MSMEs closed as many as 900 units from the existing 2500 units. The total loss due to eruption is estimated at Rp. 5 Trillion [8].

When the 2010 eruption occurred, the exploitation was beyond the expectations of many parties, resulting in more fatalities than the eruption that occurred before 2010. Signs of an explosive eruption could not be detected before. This is due to the absence of observing the amount of mass in the magma bag in the period 1988 to 2009 on an ongoing basis. Research that has been done is momentary so it can not be known how much the change in the amount of mass from time to time which turned out to be even greater. Observation of the number of masses by seismic method by Widiantoro, 2018, which was acquired in 2015 shows a large magma bag, but the dimension changes cannot be known because there is no data for the period before 2015 as a comparison. Research conducted by Rina, 2014, using gravity data from 1988, 1998 and 2011 showed that the dimensions of the magma chamber were changing but with a lag time of 10 years. Changes in the dimensions of the magma bag can indicate changes in the amount of mass under the surface of Merapi [14,17,18]. Monitoring for disasters especially volcanoes is unattractive because it does not produce economic products, but monitoring is one of the important things in people's economic development so that the direction of people's economic development can be more adapted to their environment. Volcanic monitoring is also useful for the development of both commercial and non-commercial environments. Due to the big eruption in 2010, there was a change in
the direction of material distribution to the southeast, namely towards the District of Klaten. One of the changes in the direction of the eruption is caused by the open crater which is now changing its current position towards south-southeast, namely the district of [11,12,13]. Based on observations that have been made previously based on surface morphology studies, if eruptions occur again, the Kab. Klaten is expected to be the most affected area. For this reason, it needs detailed research of beneath Merapi, so that the prediction of large eruptions that will occur can be informed more comprehensively and the results obtained can be used to complete maps of Merapi mitigation.

One very important part of this study is the detection of the potential for new eruption centers as a result of increasing mass numbers. The amount of mass will indicate the amount of energy. The more mass the greater the amount of energy. Large energy allows increasing energy used to break through weak areas. A breakthrough allows a new eruption center. Weak areas are subsurface areas that can be broken through because of gaps between layers or because of subsurface structures, one of which is a fault.

On the Merapi, there are some large faults, the Kukusan fault and several other faults. Around the fault line there are a series of volcanic mountains which became the initial formation of Merapi to Merapi today. In the fault area there are steaming steam Bibi, Mount Kendil, Mount Plawangan and Merapi new at this time. From the research that has been done before, it shows that the fault area is the area where the magma breakthrough is the center of Merapi eruption from time to time. The steam fracture area becomes a place that is easily broken through and even becomes a magma reservoir area [6,7,9,10]. This research will examine the possibility of areas that could become the center of new eruptions in the future. By conducting this study, it is expected that it can be anticipated early on about mitigating and structuring the environment of areas prone to volcanic eruption disasters, so that economic, social and environmental losses can be reduced.

![Figure 1. The peak of Merapi from Cepogo, Boyolali distric](image)

2. Research method

The geophysical method chosen to help predict vulnerable subsurface areas as weak zones is the gravity method. The gravity method is used to determine the distribution of subsurface densities. Soil / rock layers that have fractures will have different density values than those of dense areas without fractures. Existing soil layers are layers that are not possible without fractures. As a result of endogenous activity it is very possible to trigger the occurrence of weak zones beneath the surface resulting in fractures. Existing fractures can become a path of magma intrusion. Magma intrusion is the main source of volcanoes. By knowing the density distribution it can be seen that the area has experienced a change in the amount of mass or change in density. Changes in mass due to can indicate the presence of intrusion,
although it does not always increase the mass identical to the presence of magma intrusion. Using the gravity method, subsurface analysis can be performed to predict the potential for new eruption centers.

This research uses gravity data which was acquired in July s.d. August 2019. The acquisition process uses the Gravitymeter LaCosta-Rhomberg G series, Altus GPS and other supporting devices. The acquisition is carried out 5 times at each measurement point and the looping process is carried out every 3 hours. A number assist points are made to assist the looping process to minimize drift correction values. This research uses the relative gravitational field calculation process that refers to the absolute gravitational field value in Yogyakarta Volcanology as a bonding point.

Determination of measurement points refers to the 2011 Merapi gravity study. The use of 2011 data as a reference because 2011 data has more even distribution than in 1998 and 1988. The number of stations in 2011 is 195 and then to be selected into 100 points. The stations in 2019 base on the stations position in 2011. Because this is the monitoring process so the stations must be on the same position as before (Figure 3). Data of 100 points does not include data in the peak area of Merapi. The data in the peak area cannot be done yet because of the Merapi condition which is unpredictable and has effusive eruption several times. PVMBG temporarily closes the peak area of Merapi for climbing. If circumstances allow it will be carried out an acquisition to complement existing data. Map of distribution of measurement points is presented in the following figure 2.

Figure 2. Gravity Stations postion on the Merapi area in 2019
3. Results and discussion

The results of the complete Bouguer anomaly (CBA) processing in 2011 and 2019 are mapped as shown in Figure 4. In Figure 4 it appears that CBA in 2011 and 2019 have values of -10 to 85 mGal with almost the same contour pattern. Changes in value are apparent in the northwest, north and south of the study area. The low anomaly area in the northwest of the study area in 2019 is broader than in 2011, while in the northeast of the study area there is no change in the area of the low anomaly area. The high anomaly in the south and southeast of the study area increased in value by 2 to 5 mGal. The biggest increase is in the southeast. In this study the peak data could not be acquired due to the prohibition of entering the peak area as a result of the increased activity of Merapi since May 2019. The analysis carried out focused on the Merapi foot area. Based on previous research, it was explained that the change in the value of the gravitational field in the foot region is more caused by changes in the amount of mass due to aquifer / ground water. When the amount of mass of water increases, the gravitational field increases. In this study the data acquisition was carried out in the same summer as the acquisition in 2011 [3,4,5,7,9,10,11,13,15,16,18]. The results showed an increase in the value of the gravitational field. If viewed from the ongoing season, then the allegation of an increase in the mass of the aquifer is a small possibility. An increase in the value of the gravitational field can be expected as an increase in mass other than an aquifer, the presumption that there is an increase in mass / magma below the surface. As explained from previous research, the alleged process of supply of magma comes from the south and southeast. The increase in mass from the south relates to subduction in southern Java. Subduction in southern Java is a major contributor to the occurrence of volcanic ranks along the island of Java. With the increase in mass in the south allows a faster supply of magma to the Merapi reservoir, so that magma that fills the Merapi reservoir can cause eruptions.

Figure 3. Acquisition gravity at Pos Krinjing observatory of Merapi in 2019
Figure 4. Complete Bouguer anomaly (CBA) on the topographic, CBA data in 2019 and 2011

Figure 5. a. Regional gravity anomaly map in 2011 overlay with regional gravity anomaly map in 2019, b. Local gravity anomaly in 2011 overlay with local gravity anomaly map in 2019

The results of the separation of local and regional anomalies in 2011 and 2019 were mapped in Figures 5a and 5b. The 2011 regional anomaly contour map overlapped with 2019 is mapped in Figure 5a. The regional anomaly contour map shows the same pattern, namely the high anomaly in the south decreases in value towards the north of the study area. The difference is seen in value with an increase value in the south, decreasing value in the northwest and the peak area of Merapi. From the results of this separation can be seen that the increase in value in the south not only occurs locally but also regionally, so that the increase in mass is not only superficial but also deep.

Figure 5b which is a map of local anomalies in 2019 showed an increase in value compared to 2011. In general, the results of local anomalies in 2019 still had consistency of anomaly patterns against local anomaly patterns. In 2011 and 1998 there were low anomalies in the northwest, northeast, and high anomalies in the southeast to southwest. The changes consistently occur in the results in 1988 to 1998,
1998 to 2011 and 2011 to 2019. It is possible to predicted that the intrusion occur from southeast to the peak of Merapi.

The difference is seen in the peak area of Merapi due to the absence of peak data. An increase in value of 2 to 5 mGal is in the southeast to the southwest of the study area. Anomaly decreases in the northwest towards the peak of Merapi, the north and the peak area of Merapi. The decline in value in the peak region is most likely due to the absence of data in the region. Analysis is only done in areas that have measurement data.

The 3-dimensional inversion model on the horizontal plane at depth 4000 m show in figure 6. Selection into 4000 m based on previous research that the researchers have done, depth of 4000 m is the Merapi reservoir zone [3,4,15,18,19]. Density distribution with contrast density of -0.38 to 0.716 g/cc (density 2.1 g/cc to 3.1 g/cc). The inversion results show changes in the area of high density contrast areas. Change seems to extend north. Changes were seen at an elevation of 800 m, the pattern of density rising towards the peak of Merapi was not seen in the 2011 data. This indicated an increase in mass with a higher density, that in the area there was no change in elevation. From these results it can be assumed that the change in the amount of mass carrying surface does not only occur in the peak area or the area of magma reservoir, but also changes in the valley of Mount Merapi. Increasing the density value can be caused by increasing the amount of mass with a density that is greater than before. The subsurface mass is a mass that is a local and regional contribution, so it is assumed that changes occur not only locally but regionally. Regional changes can be caused by magma supply that is thought to originate from the southern part of Central Java. If the next survey changes / increases in the southeast, then to be able to convince the direction of magma supply more valid it is necessary to conduct a wider survey to the south and north of Merapi.

![Figure 6.](image)

4. Conclusion
The results of the analysis of local anomalies resulted in a large increase in anomalous values of 2 s.d 5 mGal in the southeast towards the southwest. The absence of peak data causes the value of the gravitational field anomaly change to be very large in the peak area. It is not yet possible to get a valid picture of the subsoil distribution of the subsoil mass associated with the change in dimensions of the magma reservoir, but it is possible to obtain a description of the increase in the largest mass in southeastern Merapi towards the summit. there is an intrusion process that allows the next eruption in 2020.
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