Detecting hot spring manifestations based on gravity data satellite on mountain Lawu

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Abstract. Mount Lawu is in the transition zone among Western and Eastern Java. Gunung Lawu consists of two volcanic systems separated by the East-West trending Cemorosewu Fault. The geology of Mount Lawu is dominated by Andesite Lava. Mount Lawu area has a geothermal energy prospect with indications of the appearance of hot springs and fumaroles. 2D modeling of subsurface structure of Mount Lawu's manifestation area has been carried out using gravity method. The aims of study to investigate the appearance of hot springs is related with fault structure. Data used using GGMplus (Gravity model plus) satellite image data in the form of gravity disturbance or anomaly free air with spaces each points is 200 meter respectively. GGMplus gravity anomaly data are performed bouger correction and field correction to produce a complete bouger anomaly (ABL). The ABL results present that the anomaly corresponds to the geological map, otherwise the higher topography correlated with with the smaller value of the gravity anomaly. 2D modelling and interpretation has done based on ABL results. Based on 2D modeling the appearance of hot springs is controlled by the presence of faults, moreover Mount Lawu consists of three layers of rock, namely Tuff with a density of 1.27-2.66 gr / cm³, andesite lava 2.90 gr / cm³, and basalt lava 2.99 gr / cm³. The results of study are expected be used as a reference and policy decision in geothermal development of Mount. Lawu.

1. Introduction
The utilization of geothermal energy needs attention so that Indonesia does not experience an energy crisis. For this reason, the exploration and exploitation of geothermal energy source need to be increased. Geophysical methods have a very important role in exploration of geothermal energy resource, moreover geophysical methods are used to determine the geological structural configuration and subsurface composition using parameters physics [1]. Geophysical methods are divided into four main methods, namely seismic methods, potential (gravity and magnetic) methods, and electric methods [2]. The gravity method was used in this research. The gravity method is a method based on measuring variations in the gravitational field on the earth's surface. The advantage of the gravity method is that it does not damage the environment and has a relatively low cost compared to other methods. Research using gravity method for geothermal has been done in several volcano in the world [3-11]. Currently, there are gravitational field data from satellites is available, one of data is GGMplus which will be used in
this research.

The area of Lawu Mount has an energy storage of 195 MWe [12]. Lawu volcano consists of two volcanic systems separated by the Cemorosewu Fault with East to West direction. The volcanic system were occurred in southern part of the Cemorosewu Fault and it is called Old Lawu volcano or Jobolarangan volcano. Old Lawu is older (Pleistocene) than the Young Lawu Volcano system which located in the northern part of the fault (Holocene) [13].

The aims of study are to interpretation and analysis of subsurface structures beneath Lawu Mount area corelated with hot spring manifestations on the surface using GGMplus secondary data in the form of a gravity disturbance or free air anomaly.

2. GGMplus Satellite Image (v. 2013)

GGMplus Satellite Image (v. 2013) usually called GGMplus is a gravitational field model based on data from the GRACE satellite (ITG2010), the GOCE satellite (TIM-4), EGM2008 and topographic gravity. GGMplus provides five gravitational field functions, namely gravitational acceleration, gravity disturbance, north-south, and East-West vertical deflection and qasigeoid elevation. The data is presented in a 5° × 5° matrix in the form of a grid with spacing between 200 meters in the North-South direction [14].

The GGMplus gravity data used is the gravity disturbance data. Gravity disturbance is a term used in the field of geodesy, in the field of geophysics it is called a free air anomaly. GGMplus gravity disturbance anomaly is data obtained by subtracting the GGMplus gravitational acceleration value from the normal gravity value on the surface (free-air correction) [15]. Figure 1 shows the gravity disturbance map from the GGMplus data with located in 110° – 115°E and 5°-10°S.

![Figure 1. The gravity disturbance map from GGMplus data with located in 110° – 115°E and 5°-10°S](image)

3. Geological setting of Lawu Mount

Lawu Mount is transition zone between western and eastern Java. Lawu Mount consists of two volcanic systems separated by the Cemorosewu Fault trending East - West [13]. The continuous decline in the Quaternary has resulted in the Lawu mountains in the North. At the beginning of the Pliocene, the activity of Mount Jobolarangan or Old Lawu took place, which was then followed by the collapse of the northern slope of the volcano along the Cemorosewu Fault, with geological age around middle of the Pliocene. Furthermore, the next magmatism activities forming Young Lawu cone on the Northern edge of the fault [16]. The geological map of Lawu Mount is present in Figure 2.

Based on the geological map of Ponorogo sheet, Central Java [16], the rocks around Lawu Mount from old to young consist of:
1. **Qvjt**, Jobolarangan tuff, consists of lapilli tuff and pumice breccia.
2. **Qvbt**, Butak tuff, consists of tuff andesite composition.
3. **Qvbl**, Butak lava, consists of black and gray lava.
4. **Qvjb**, Jobolarangan breccias, consists of local volcanic breccias inserted with lava, both of which are composed of andesite.
5. **Qvsl**, Sidoramping lava, consists of lava composed of andesite, dark gray, porphyritic.
6. **Qvjl**, Jobolarangan lava is andesite lava containing andesine, quartz, feldspar and a little bit of hornblend.
7. **Qvl**, Lawu volcanic rock, consists of tuff and volcanic breccia.
8. **Qval**, Lava Anak is andesite lava that flows from the center of G. Anak.
9. **Qvcl**, Condrodimuko Lava is andesite lava that was released from the Condrodimuko crater to the Southwest.
10. **Qlla**, Lahar Lawu, components of andesite, basalt and a little pumice.

Figure 2. Geological map of Lawu Mount [16]

4. **Correction of gravity data**

The gravity data GGMplus which used in this research is data in the form of a gravity disturbance or free air anomaly and still need some correction.

4.1 **Bouguer correction**

Bouguer correction is a correction to calculate the rock mass between the observation point and the plane point [17][18]. Bouguer corrections are performed to calculate the gravitational pull caused by the thickness and density of the rock as presented in equation 1.

\[
B_C = 0.04192 \rho h
\]  

(1)

Where \(B_C\) is the bouguer's correction, \(\rho\) is the density and \(h\) is the height or elevation of the observation point [17][18].

4.2 **Terrain correction**

Terrain correction was performed to correct for the influence of irregular mass distribution around the measurement point as following equation 2 [18]. In the bouguer correction, it is assumed that the measurement point in the field is on a very wide flat plane. Meanwhile, the reality in the field often has
an undulating topography such as valleys and mountains. So, if only the bouger correction is done, the results will be less than perfect [19].

\[ T_C = 2\pi \left( (r_1 - r_0) + \sqrt{r_0^2 + z^2} - \sqrt{r_1^2 - z^2} \right) \] (2)

Where \( T_C \) is terrain correction, \( r_1 \) is outer radius (meter), \( r_0 \) is inner radius (meter) and \( z \) is the difference in the height of a field with the height of the observation point [18].

4.3 Complete bouger anomaly

Complete bouger anomaly (CBA) is an anomaly resulting from terrain correction, where the anomaly is only influenced by the density variation below the surface. The effect of this density variation can be interpreted as an initial image of the estimated geological structure in the study area [15]. The complete bouger anomaly equation can be shown mathematically by equation (3)

\[ CBA = FA_A - B_c + T_c \] (3)

With CBA is a complete bouger anomaly, \( FA_A \) is a free air anomaly, \( B_c \) is bouger correction, and \( T_c \) is terrain correction [18].

5. Geothermal system

Geothermal system is a process of fluid convection in the upper crust in a confined space, transferring heat from the heat source to the heat sinks on the surface. Geothermal systems are mainly built by the presence of heat sources, reservoirs, and fluids. The heat source is magma that freezes under the surface of the earth. Igneous rocks resulting from freezing magma have high resistivity characteristics because they do not contain fluid either chemically or physically. These rocks conduct heat through contact with surrounding rock. The heat that propagates in the rock heats the fluid flowing in the reservoir [20].

![Geothermal system model at terrain condition](image)

Figure 3. Geothermal system model at terrain condition [21]

6. Research method

The research data used secondary data GGMPlus 2013 in the area of Lawu Mount with an area of 24.03716 × 24.77246 km. data is free air anomaly data and has 12,882 observation points with a distance each point is 200 meters respectively.

The research was carried out in several stages including data processing, modeling and
interpretation. The gravity anomaly data obtained is in the form of secondary data from GGMplus which consists of the coordinates of the observation points of the research area and the free air anomaly. The coordinate data of the GGMplus observation points were converted from geographic coordinates to UTM coordinates using the Surfer software. GGMplus gravity anomaly data needs to be corrected for gravity to obtain a complete Bouguer anomaly, namely Bouguer correction and terrain correction. Quantitative interpretation is carried out by performing 2D modeling of the complete Bouguer anomaly which is correlated with geological information on the research area.

7. Result and discussion
Free air anomaly is a free air gravitational field anomaly in the topography. The free air anomaly does not take into account the field effect of the observed altitude [14]. The contour map of free air anomaly is shown in Figure 4, ranges from 30.8 mGal to 232.3 mGal respectively. High anomaly values indicated in orange-pink represent the presence of Lawu Mount and low anomalous values indicated in blue indicate lowlands. The topography map of Lawu Mount shows at figure 5, that the contours of the free air anomaly are still influenced by topography. Moreover, there are positive correlation between topography and free air anomaly.

A digital elevation model that is used as a mass source model in terrain correction using SRTM data provided by the CGIAR-CSI GeoPortal with resolution 90 meters; elevation gravity data point from ERTM2160; and density 2.67 gr/cm³ which is the average density of the Earth's crust [22].

Figure 4. Free air anomaly map in Lawu Mount.
Figure 5. Topography map of Lawu Mount.

Figure 6 shows the complete Bouguer anomaly (CBL) value in the study area ranging from -8.7 mGal to 52.3 mGal. The resulting anomaly is inversely proportional to the topographic conditions. Based on geological history, at the beginning of the Pliocene the activity of Old Lawu Mount took place which subsequently collapsed on the northern slope in the middle of the Pliocene. Moreover, the activities of magmatism formed Young Lawu Mount which located in the northern part during the Holocene era [16]. It has positive correlation that the geological activity is causing Young Lawu Mount have a low anomalous.
Figure 6. Complete bouguer anomaly map of Lawu Mount

2D modeling in this study uses forward modeling. The device used for subsurface modeling is Geosoft Oasis Montaj (GM-SYS). The principle of GM-SYS is to equalize shape of the observed anomaly, which is a dotted line with a calculated anomaly in the form of a firm line. 2D subsurface models were created to supporting information based on geological data, surface features and rock density parameters.

Figure 7 shows the A-A’ section is dominated by two rock types based on variations in rock density. Tuff has a density of 1.89 gr/cm$^3$ - 2.63 gr/cm$^3$ and andesit lava with a density of 2.90 gr/cm$^3$. There is a fault in the A-A’ model which corresponds to the geological map of the study area, namely Cemorosewu fault that controls the appearance of Pablenan hot springs.

The B-B’ section is dominated by three rock types based on variations in rock density. Tuff has a density of 1.44 gr/cm$^3$ - 2.61 gr/cm$^3$, Andesite lava with a density of 2.90 gr/cm$^3$, and basalt lava with a density of 2.99 gr/cm$^3$. There are three faults in the 2D model of section B-B’ which correspond to the geological map and this fault is a Cemorosewu fault that extends from West to East. The fault controls the presence of Cumpleng hot springs as presented at figure 8.

The C-C’ section has a North to South direction with cuts the fault to control Tasin hot springs in the South (Figure 9). The length of section model is 3.2 km with a depth of 3.8 km. There are two types of rock dominated; first one is rock with a density of 1.27 gr/cm$^3$ - 2.66 gr/cm$^3$ is tuff and andesite lava with a density of 2.90 gr/cm$^3$. The existence of faults in 2D modeling of the C-C’ section corresponds to the geological map.

2D modelling of the D – D’ section with a South-North direction is presented in figure 10. The incision length of model is 3.9 km with a depth of 3.8 km. The D-D’ section is dominated by the same rock layer of A – A’ section based on rock density values. Rock with a density of 1.68 gr/cm$^3$ - 2.63 gr/cm$^3$ corresponds to the tuff and andesite lava has a density of 2.90 gr/cm$^3$. There is a fault at the southern part of the incision that controls the appearance of Nglerak Hot Springs.

The E-E’ section with a Southwest-Northeast trajectory slice a northwest-southeast trending fault that extends to the top of Mount Lawu (Figure 11). The modeling has a depth of 3.8 km and an incision length of 3.3 km. There are three types of rock layers based on rock density values. The rock layer consists of tuff, andesite lava, and basalt lava. Basalt lava has a density value of 2.99 gr/cm$^3$. Tuff with a density of 1.73 gr/cm$^3$ - 2.66 gr/cm$^3$. There is a fault which corresponds to the geological map and controls the appearance of three hot springs in the area. The hot springs are Jenawi hot springs 1, Jenawi hot springs 2, and Mangli hot springs.
Figure 7. 2D subsurface model of A-A' section

Figure 8. 2D subsurface model of B-B' section

Figure 9. 2D subsurface model of C-C' section

Figure 10. 2D subsurface model of D-D'

Figure 11. 2D subsurface model of E-E' section

8. Conclusions
The conclusions of study are the boundary of the geothermal prospect at Lawu Mount is in an area that has a rock structure of andesite lava and the presence of manifestation. 2D subsurface models using the forward modeling method indicate the existence of faults that control the hot springs on Lawu Mount. 2D subsurface modeling in the Lawu Mount area consists of three rock layers, namely tuff, andesite lava, and basaltic lava. Tuff has density values range from 1.27 to 2.66 gr/cm$^3$, andesite lava has a density value of 2.90 gr/cm$^3$, and basalt lava has a density value of 2.99 gr/cm$^3$. 
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