Preliminary Study: Identifying the Heat Source of Hot spring Discovery at Non-Volcanic Region with Gravity Method

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Abstract. Gravity method is one of the geophysical methods that’s using variation of gravity value caused by density variation of subsurface. Gravity method has been utilized for many purposes such as understanding the geological information about one area or understanding the subsurface structure. This study is using gravity method to identify the heat source from the geothermal manifestation (hot spring) which is located in the non-volcanic region in North Java. Gravity data was obtained from WGM 2012 satellite data that can be downloaded at BGI website and processed using Oasis Montaj software. Data processed using horizontal derivative method to enhance the boundaries resolution of the possibility geological structures location in the study area that is predicted to be the way of the heat source of hot spring manifestation. The result of this study shows that the heat source of the hot spring in Northern East Java is probably coming from Lasem Volcano's heat source. The result can be proven by the similarity of the Bouguer Anomalies value between the Lasem Volcano region and the manifestations distribution area, which varies in 174-185 mGal. Besides that, Lasem Volcano is the closest volcano from the manifestation with a distance of approximately around 27 km.

1. Introduction
This study is discussing geothermal manifestations that exist in non-volcanic regions. In a non-volcanic region, geothermal manifestation is barely found because it is located too far from the heat source. But geothermal manifestation sometimes exists in the non-volcanic area. An example of this case can be found at Jatirogo, Tuban. Jatirogo is located on Wonocolo Formation that is dominated with limestone [1]. However, the interesting case here is hot spring manifestation can be discovered in this area.

The primary goal of this study is to understand how the heat source can reach the manifestation area. To help us more understand the subsurface characteristic of the manifestation area, gravity method was applied in this study. Gravity method that used in this study is the satellite gravity method. Satellite use to record the wavelength component of the earth as a correction for measurement on the surface. However, this study can be developed and specified for potential studies by increasing the accuracy and spectrum of their waves. The example of study about satellite survey is done by GRACE (German Aerospace Center Gravity Recovery and Climate Experiment) to map temporal variation of gravity to the dynamic mass of water [2].
1.1. Regional Geology

Based on similarities of morphological and tectonic setting, east Java area and madura are divided into seven zones [3] such as:

1. Quaternary volcanoes zone
   This zone occupies the middle part along Solo zone, except for Muria mountain which occupies alluvial plain of North Java.

2. North Java alluvium plain
   This zone is divided into two parts, begin from eastern part from Surabaya to the northwest and the western part from Semarang to the east and ends in the Java sea.

3. Rembang zone
   This zone is anticlinorium that extends in the west-east direction. Starting from the east of Semarang to the north of Rembang.

4. Randublatung zone
   This zone is synclinorium that extending from west of Semarang to the east of Wonokromo

5. Kendeng zone
   This zone is anticlinorium that extending from Semarang and then it narrows to the east until north of East Java. This zone is generally formed by volcanic deposits, sandstone, claystone, and marl.

6. Solo zone
   This zone divided into 3 sub-zone (Blitar sub-zone, Middle Solo sub-zone, and north Ngawi sub-zone)

7. Southern mountain zone (East region)
   This zone extends along the southern coast of East Java and Wonosari to the most eastern of Java Island. The topography of this zone is mostly formed by limestone and volcanic material.

Based on the physiographic map division below, the research area is included in the Rembang zone (Figure 1). This zone consists of folded ridges (anticlinorium) that extend with west-east direction start from north of Purwodadi via Blora, Jatirogo, Tuban, and ends in Madura island.

![Physiographic Map Division of Central Java and East Java](image-url)

**Figure 1.** Physiographic Map Division of Central Java and East Java [4]
The northern part of the East Java Basin (Kendeng Zone, Rembang Zone, Java Sea Shelf Zone, and Randublatung Depression Zone) has two periods of time that caused the relative direction of the magmatic path or its tectonic pattern change [3], i.e.:

1. In Paleogene Era (Eocene-Oligocene), which was oriented northeast-southwest. This pattern causes the northern part of East Java Basin to have a tectonic strain regime, indicated by the pre-tertiary age bedrock lithology which shows a northeast-southwest trending accretion pattern in the form of the orientation of faults in bedrock, horst, and graben.

2. In Neogene Era (Miocene-Pliocene) it changed to the relative east-west, which was a compression tectonic regime, resulting in folds of geological structures, factoring faults, and causing the North East Java Basin to rise.

The condition of the folding structure in the northern part of the East Java Basin is generally oriented west-east, while the fault structure is generally northeast-southwest trending, and there are several upward faults trending east-west.

2. Methodology
This research analysis is based on two approaches: geological and geophysical analysis. The data used for geophysical analysis was obtained from Bureau Gravimetric International (BGI) website: https://bgi.obs-mip.fr/, and focused on WGM 2012 data type that has 1’ resolution and already form in Complete Anomaly Bouguer (CBA) data [5]. The boundary of the research area is around longitude 110.5 until 112.5 and latitude -8 until -6.5, and there are 2806 points of CBA data in that region (Figure 2).

According to the geological assumption, the processing that is used in this geophysical analysis is focusing on structure/edge identification. A numerical derivative method used to process the data is Horizontal Gradient Magnitude (HGM). HGM was used to enhance the anomaly contrast resolution. HGM is formed by a bidirectional horizontal derivative (North-South and East-West direction) that is calculated to popping the positive value, which will be categorized as the probability of the geological structure location [2]. Then the HGM equation is:

\[ HGM = \sqrt{\left( \frac{\partial g}{\partial x} \right)^2 + \left( \frac{\partial g}{\partial y} \right)^2} \]  

Furthermore, that equation is resembling a quadratic addition from the x-direction and y-direction derivative of the anomaly. Inspired by the study about the utility of free software in gravity and magnetic method [6], this research processing will be done using open-source software: Oasis Montaj Viewer and USGS GX version 64.
3. Discussion

3.1. Geological Analysis

The main interest of this case is the location of the manifestation which is not distributed in a non-volcanic zone and formed on the top of limestone. To understand this case, a geological analysis will be used in this study. The geological analysis will be described regionally because information about the real condition of the manifestation is limited. Furthermore, based on the regional geology study of the Northern Java Region, founded that the heat source of the manifestation is probably obtained from the existence of the geological structures around them. 2 assumptions can be considered based on [7] such as:

1. Sedimentary Basins

Sedimentary basin geothermal system is formed from the heat that appears due to layering sequences of permeable and impermeable strata that alternately. Go along with this research location is around carbonates rock/limestone (permeable), there is a possibility of this type of heat source, but considering that the sediment thickness is quite low due to the subduction process, there is a justification to choose another assumption

2. Off-flow from Volcanic Geothermal Systems

This system is formed from the off-flow of volcanic geothermal areas (high-temperature), and heating groundwater by direct contact with the hot ground or mixing with deep reservoir water. That assumption (contact and mixing) could happen because of the existence of geological fractures. Resemble with this research problem that there is a discovery of some of the geothermal manifestation in the around the non-volcanic zone, around Northern Java. However; there are high-temperature geothermal areas around Eastern Java (a huge of geothermal prospects distributed around Eastern Java and include the northern region [8], and quite recognizable to correlate with this geothermal system type. Furthermore, in the area also found strike-slip fault (sinistral), and distributions of fractures that can be considered as the pathway of the heat.

Furthermore; to confirm the previous opinion [9] that either Lasem Volcano or Senjong Volcano, both it have lava flow to the southern area and the same magma evolution (partial melting of the mantel due to the subduction process). Then, for the brief conclusion, we can say that the heat source of the manifestation is started from Lasem Volcano, then going to the south to Senjong Volcano, and leaking to the west through the fractures/faults (Off- flow from volcanic geothermal systems).

3.2. Geophysical Analysis

As seen in figure 3, manifestation location is distributed in around slightly low CBA value (174-185 mGal), similar to the anomaly variation around Lasem Volcano and Senjong Volcano. The similarity shows a possibility of the same subsurface condition, such as rocks content or even in the hydrology aspects. Then, according to the previous opinion that the heat source of manifestation was coming from Lasem Volcano and migrated by the faults/fractures, it can be proven by looking at the HGM value pattern around the manifestation and the suspected volcanoes. Figure 4 shows that there is a structured pattern that can be directing the pathway of the heat from Lasem Volcano to the manifestation. This pathway was described with marked by dashes lines that estimated from the high positive value of HGM (indicates the location of the anomaly contrast/suspected structure identification).
4. Conclusion
The horizontal derivative gravity method has been applied to predict the heat source distribution pathway to the hot spring manifestation in Jatirogo. The response of bouger anomalies shows the similarity of value bouger anomaly values between Lasem Volcano and manifestation distribution which varies between 174-185 mGal. This confirms the assumption of heat source distribution to the hot spring manifestation in Jatirogo, Tuban controlled by Lasem Volcano.

Moreover, another function of the derivative method is given to enhance the boundaries resolution of possible geological structures located in the study area. The geological structure for this study is very important to predict the heat source pathway to the manifestation. Geological structure direction (strike and dip) also useful to help us understand how the heat source transferred from Lasem Volcano to the nearest manifestation in Jatirogo that approximately has 27 km distance.
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