Re-modeling kaligarang fault base on satellite gravity data

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Abstract: The Kaligarang River heading North-South divides the region of Semarang. The Dutch Colonial Government recorded the territory of Semarang on January 19, 1856, shaken by an earthquake on the mainland epicenter with the strength of the V-VI MMI. Fault Kaligarang has a sliding rate of slip (slip rate) of 4.5 mm per year. The value of rock slip rate is relatively very small, but if accumulated over a long period, its value can increase and it will form an earthquake when energy is released. Kaligarang fault is still active and can cause another earthquake. Estimates of active Kaligarang fault are analyzed using different analytical methods by combining 3 methods (magnetic, gravity, and geological). Preliminary studies were conducted using the gravity method used satellite data. The purpose of this study was to determine the ability of satellite data to be used as supporting data for preliminary research and also as complementary data. There are similarities in the results of inversion modeling with using GgmPlus data and geological data in the field. This result cannot prove the kaligarang fault because kaligarang fault is a transform fault. The distribution of subsurface mass can prove the existence of faults in the Semarang area but not at all, so that terrestrial data are still needed to obtain a more complete subsurface geological structure. Others method are needed to complete and prove the Kaligarang fault is active.

1. Introduction

A geological disaster is a natural disaster that cannot be avoided by humans. A geological disaster is a form of natural disaster that cannot be controlled by humans, but humans are given the ability to be able to understand natural phenomena that occur so that the number of victims, the level of damage or loss can be reduced. One of the natural disasters that cannot be controlled by humans is an earthquake due to the activity of fault. Current technology can help humans to be prepared when a disaster happened, although not all technological advances can predict accurately. If information on geological and other changes is considered, the impact of disasters can be reduced. Faults are the result of plate tectonic dynamics, when a fault moves, a very large release of energy occurs, which will cause a large impact. Therefore, we should understand how a fault will be active once it is formed.

Geological data of the Semarang area, which is located in the northern part of Java Island, is a relatively stable area to earthquakes which are caused by plate subduction. The subduction plates are in the south of the island of Java. As we know, the activity of a plate will trigger the activity of other plates around it. If one plate is active, it can trigger the activity of other plates [9]. The existence of an active fault which is the source of the earthquake needs to be considered. The Kali Garang River flows in the Semarang region in the north - south direction. This river valley is thought to be an active fault from the Tertiary to Quaternary era. The Dutch colonial government noted that the Semarang area on January 19,
1856 was shaken by an earthquake with an epicenter on the mainland with the power of the V-VI Modified Mercalli Index (MMI). The MMI V-VI force is described as an earthquake felt by everyone, objects falling down to destroy semi-permanent buildings and trees, and causing liquefaction in certain places [11]. The cause of this earthquake is estimated to be caused by the Kali Garang fault. Research on tectonic activity in Semarang was conducted by Thanden et al. (1996), Pramumijoyo (2000) and Simandjuntak (2003), research on the Kali Garang fault was carried out by Helmy (2008), Poedjoprajitno et al. (2008) and Fahrudin et al. (2011) [4;8;11;12;15].

The Kali Garang Fault is an active fault that consist of young rocks from the south of Semarang City and continues to the Java Sea. Observation of Landsat images in the Semarang area shows the direction of the geological structure of Kali Garang fault. Geological research found fault manifestations which include fault lines, uplifting of river terraces, creeping soil movements, shifting rocks and fractures that divide the Quaternary rocks of the Damar Formation. Based on geological data, the Kali Garang fault with a north - south direction is an active fault [10]. Initial identification was carried out by observing morphology in the Kaligarang area, showing the presence of fault lines, uplifting of terraces and chain structures in the river channel [7]. The existence of horizontal fault activity in the Kaligarang river path is characterized by changes in flow patterns, which control the distribution of pointbar rows resembling tensile basins [5;7]. Research on the Kali Garang fault that is often carried out generally refers to a geological review. Research with the geophysical method was carried out by Dadan, et al, 2014 with a gravity study. The study was conducted to identify the relationship between geological structures beneath the surface with the phenomenon of landslides [4].

Previous research has shown that Kaligarang fault is active and can be active again when other faults around it are active. Kaligarang fault research is conducted to determine the activation of Kaligarang fault, so that the results of the analysis can be used as one of the more appropriate disaster mitigation suggestions to minimize the impact of sustainable disasters.

The method used in this study is a geophysical method, one of which is gravity method. Gravity survey is a survey that requires a lot of costs for institutions that do not have their own measuring instruments. Due to the limited amount of gravitymeter causes the high rental price of the tool. To investigate the cost of research, for initial research can be done using satellite data available for free. Satellite data provided by BGI is one of the current high resolution satellite data which is about 220 m. The results of the analysis using satellite data are expected to provide preliminary results on the mass distribution below the surface of the city of Semarang. In further research using terrestrial data can be found more complete the structure below the surface of the city of Semarang, especially the fault of Kaligarang.

1.1. Geology of Semarang

The city of Semarang has a geological structure that is a fault that consists of a normal fault, reverse and a strike-slip fault. Normal faults have a west-east direction and some of them move north. Transformat faults have a north-south to northwest-southeast direction. The fault was found in the Kerek Formation, Kalibening Formation and Damar Formation. Age of rock formation in the Quarter and Tertiary ages (Wardhana et al., 2014). Poedjoprajitno et al (2008) explained that the city of Semarang and its surroundings changed in several periods of deformation [11;14]

Fault structures produced in Tertiary times in the north-south, west-east, and northeast-southwest directions. The north-south strike slip fault is a right-hand fault. Faults to the west-east direction are faults to the left, while normal faults have northeast-southwest directions. Faults that have been inactive for a long time show activity in the Quarter. The fault that has a north-south direction is active again as a left strike slip fault, which is included in this fault which is the Kaligarang fault. Faults that have a northeast-southwest direction are active again as reverse faults, which are included in this faults, namely the Pengkol River Fault and Kreo River Faults, and faults that have an active north-east direction return as reverse faults (Figure 1). [15]
In the city of Semarang there are also anticlin and cycline structures. The anticline structure found in Semarang City is the Bergota anticlin. Bergota Antiklin passes through Bergota Hill, Gunung Sawo and Pleburan along ± 4 km east-west. Candi anticlin identified from the results of measuring the direction and slope of the rock layer in the northern area of the Candi Baru, the Langas River, and the Gayam River. Antiklin Candi passes Tegal Sari to the south of Kintelan along 2.5 m towards the northwest-southeast. Antiklin Karanganyar Gunung, 1.5 km east-west. The synclinal structure in Semarang City is located between the Bergota anticlin and the Candi anticlin. This asymmetrical synclinal is 2 km to the northwest-southeast, with the southern part sloping more than the northern part [10,14].

2. Method

The method which chosen is gravity method, using Kaltec – BGI data. Kaltec data is gravity acceleration data. The Kaltec data downloaded on August 1, 2020 [http://murray-lab.caltech.edu/GGMplus/index.html]. In addition to gravity data, BGI also provides elevation data (ERTM) with the same grid as gravity acceleration data [https://bgi.obs-mip.fr/data-products/gravity-databases/land-gravity-data/]. The data available in BGI is free data so it can be used free for research. ERTM data and g observations from GGM-Plus are mapped as in Figures 2 and 3.

The gravity data provided by BGI is the gravity data of mathematical calculations combined with some terrestrial data. Gravity acceleration data were processed with some correction and obtained complete Bouguer anomaly. Separation of anomalies using upward continuity so that local and regional anomalies are obtained [1,6,9]. Subsurface 3D invers modelling of Complete Bouguer anomaly and local anomaly use Gravblox v.1.6. The inverse method is a method based on mathematical equations so that more valid and detailed modeling can be obtained [2,5]. A cross section was selected for analysis
Figure 2. Topography of Semarang by ERTM data

Figure 3. The gravity acceleration map contour of GGM Plus data
3. Results and discussion
GGm Plus data has very detailed data so that the observed value of g is obtained more detailed compared to ordinary terrestrial data. Generally terrestrial data generally spaced 500 m to 2000 m. GGm plus data has a wavelength of 10 Km. If the wavelength is used for a narrow research area, then the results are not good. So terrestrial data is needed to complete it. Terrestrial data is the main data while satellite data as a complement. Terrestrial data can be combined with satellite data but a correlation between the two data must be known. If the correlation is 0.8 to 1 then both data have a good correlation. In addition the contour patterns of GGmPlus data and terrestrial data should have the same trend. When the two data are mixed do not change the existing pattern. If there is a change, then the change that occurs does not change the general pattern that exists in the research area.

In this study only satellite data was used. Further research will use terrestrial data and a mixture of both. The dimension of research area in coordinate 9216000 m to 9230000 m S, 4240000 m to 4420000 m E. Figure 4, the contour pattern of GGmPlus produces high anomalies in the north and low anomalies in the south of the research area. The contours show a pattern that is predicted as a Kaligarang fault. The area around the kaligarang fault is indicated by low anomalies Which high anomalies separating low anomalies on the right and left side. Kaligarang fault produces the Kaligarang river valley. Kaligarang reverse fault straight South - North, starting from Ungaran area towards the center of the city semarang.

The result of the observation process is a complete Bouguer anomaly on the flat plane mapped as shown in Figure 5. The flat plane method is used for the inversion process if the software does not use topographic input. Gravblox 3D modeling does not use topographic input, so gravity field values are required in the same field. The flat field method is a mathematical method that recalculates the gravitational field at a certain height, so that the measurement value in the topography will be recalculated at the same height. The height of the selected flat field is the maximum height of the research area (Figure 5).

![Figure 4. Kaligarang fault on The gravity acceleration map](image-url)
Figure 5. Complete Bouguer Anomaly map on flat plane (500 m).

The CBA on the flat plane value is 4 mGal up to 20 mGal. Its value increased to the East, South and North-East of the research area. The CBA value in the centre to east part of the research area is 12 mGal to 18 mGal. The lowest value in the centre to west side of research area. The lowest CBA in the blue to purple colour. The topographic pattern of the research area shows that the research area consists of lowland areas and hilly areas. The CBA contour pattern has a different contour pattern than the topography, so it is possible that there is a variation of the subsoil distribution in the research area. If the anomaly value distribution is considered to be the density value distribution, then the west side of the research area is the area with lower density value compared to the east side. The next step to indentify the subsurface distribution, inversion method must be done.

Subsurface mass modeling used gravblox software v.1.6. The result of inversion is density value of the local Bouguer anomaly. The density value are 2.38 gr/cc to 2.86 gr/cc. The 3D modelling show that the northern part of Semarang is an alluvial formation. The alluvial formation areas have low density values so the gravity response is small. The southern region is an area of volcanic rock that is part of the Ungaran volcanic rock. Due to the volcanic rock, the gravity response is large [3;15]. Volcanic rocks have a greater density value than alluvium. In the central part of the research area a basin model is produced. The results of 3D modeling can be traversed for analysis. The selected cross section is 9222000 m (Figure 6). The selection of cross section is based on previous geological studies [8;15]. At the cross section 425000 m to 436000 m, the part of fault appears on the surface. The fault direction is in North – South (Figure 6). The results of inversion modeling in the cross section on 9222000 m, produce a distribution of density distribution at depths of up to 4000 m with a lower density value compared to deeper layers. As explained in geological research, subsurface rocks are dominated by surface alluvium, conglomerates of breccia and volcanic rock in the lowest layer. The appearance of high density at 425000 m to 436000 m is suspected as a normal fault. From the results of field geological observations, there are normal faults at 425000 m to 436000 m, so a match is obtained between the results using satellite data and geology in the field [13;15].
Figure 6. Gravblox 3D density modelling in line 9222000 m

4. Conclusion
GGmPlus Satellite Data can be used as preliminary research. There are similarities in the results of inversion modeling with using GgmPlus data and geological data in the field. This result cannot prove the kaligarang fault because kaligarang fault is a transform fault. The distribution of subsurface mass can prove the existence of faults in the Semarang area but not at all, so that terrestrial data are still needed to obtain a more complete subsurface geological structure. Others method need to complete and prove that Kaligarang fault is active.

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