Subsurface Modeling Based on Gravity Satellite Data in the Paser Area, East Kalimantan, Indonesia

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Abstract. One of the areas in Indonesia that are at risk of being affected by disasters is East Kalimantan. East Kalimantan is designated as IKN (State Capital City) by the government of the Republic of Indonesia. East Kalimantan was chosen as the new IKN due to its geographical location in the middle of the Indonesian archipelago and the low level of disaster risk. However, it is necessary to make efforts to mitigate disaster and to know the subsurface structure as initial information for making IKN. Integration of various scientific fields is needed to recognize disaster risks. One of the fields of science that is used is Geophysics. Methods in geophysics that describe the shape and the geological subsurface based on variations in the earth‘s gravitational are known as the gravity method. The data used is TOPEX Satellite observation data, in the form of FAA (Free Air Anomaly), a Complete Bouguer Anomaly Map obtained through Bouguer correction, and terrain that has been through adjustment of the range of values of the correction to produce a representative map. The inversion modeling based on the complete Bouguer anomaly used in this study consists of two sections. By orienting at the epicenter of the earthquake as a reference. With contrast density from −0.863 mgal to 0.932 mgal. This indicates that there is an anomaly beneath the surface.

Keywords: Disasters · Geophysics · Gravity Method · Anomaly · Density

1 Introduction

Indonesia is located at the confluence of three world’s major plates, known as the Indo-Australian plate, the Pacific plate, and the Eurasian plate. Therefore, Indonesia is very risky in terms of natural disasters. The occurrence of volcanic eruptions and earthquakes due to the movement of these plates. Plate movements which are seismic activity, trigger the formation of active faults. Therefore, the identification of geological structures in the form of faults in an area is very necessary for development planning and disaster mitigation, especially considering that Indonesia is an area with high disaster potential. One of the areas in Indonesia that is at risk of disaster is East Kalimantan [1]. Although this area is classified as having a low level of disaster risk, East Kalimantan may also experience natural disasters. However, in the last few years, there have been several

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earthquakes on the island of Kalimantan, some of which are even destructive earthquakes. As happened on March 1, 2022, the epicenter of the earthquake was on land 46 km northwest of Paser. According to the Metrology, Climatology and Geophysics Agency (BMKG), the earthquake, which had a hypocenter at a depth of 10 km, and an epicenter 46 km northwest of Paser, could be felt on the MMI II-III scale. Based on BMKG information, the trigger for this earthquake was the Meratus Fault. This earthquake proves that the earthquake fault is still active after having caused a destructive earthquake on October 25 and 26, 1957, and then through the release of energy of magnitude 6.1. This means that the earthquake caused a disaster. The earthquake incident can at least answer that the island of Kalimantan is not completely safe from earthquakes or other disasters [1, 2].

2 Material and Methods

The distribution of earthquakes on the island of Kalimantan is not as much as in other areas in Indonesia, such as those in Sumatra, Sulawesi, Java, Maluku, and Papua. However, there were several earthquakes, especially on the mainland of the island of Kalimantan, especially in North Kalimantan and East Kalimantan. Several earthquake epicenters were also found in South Kalimantan and West Kalimantan. These earthquakes generally have shallow depths (less than 50 km) and are estimated to be associated with active faults [1, 3]. Earthquake sources that are considered for preparing an earthquake hazard map in Kalimantan are those located around the island of Sulawesi, namely the North Sulawesi subduction, the Palu Koro Fault, and the Makassar Fault. This resulted in the magnitude of the value of the earthquake acceleration on the bedrock on the island of Borneo dominantly less than 0.05 G (Gravity). Only some areas in North Kalimantan and East Kalimantan have earthquake acceleration values ranging from 0.05 G to 0.2 G [4]. This earthquake acceleration value is relatively small, in stark contrast to the earthquake acceleration values around the Sumatra Fault, Palu Koro Fault, and Fault in the Jaya Wijaya Mountains which reach greater than 0.5 G [5].

The non-seismic geophysical method that is widely used in the determination of the structure of subsurface anomalies is the gravity method by paying attention to gravity anomalies in a particular area [6, 7, 8]. The parameter used in this method is the difference in subsurface density values. Newton's law of attraction between particles is the basic physics principle underlying the gravitational method. Newton's law states that the attractive force between two particles with masses m_1 and m_2 separated by a distance $\mathrm{r}_2 - \mathrm{r}_1$ from their center of mass is proportional to the product of the masses m1 and m2 and inversely proportional to the square of the distance [9]. The force is described as follows:

$$F_{12}(\overrightarrow{r}) = -G\frac{m_1(\overrightarrow{r_1})m_2(\overrightarrow{r_2})}{|\overrightarrow{r}|^2}\hat{r} \tag{1}$$

where $F_{12}(r)$ is the force acting on m_2 because m_1 is the mass of particle 1 and m_2 is the mass of particle 2. While G is the general constant of gravity which is 6.67×10^{-11} $\mathrm{Nm}^2\mathrm{kg}^{-2}$[5].

Earth's gravitational field g only has one direction, namely toward the center of the earth. The direction of the gravitational field is defined as the vertical direction. The strength of the earth's gravitational field caused by anomalous objects has a direction that varies with the vertical direction depending on the position of the anomalous object. The changes in the earth's gravitational field strength that are caused by local anomaly objects are called gravitational anomalies [10]. The gravitational field anomaly is the gravitational field value that is caused by the difference in density contrast values below the earth's surface. Earth's gravitational field anomaly is measured or measured together with the Earth's gravitational field [11, 12]. Mathematically, it can be defined that the gravitational field anomaly in the topography or position (x, y, z) is the difference between the observed gravitational field in the topography and the theoretical gravitational field in the topography. Or it can be expressed as follows:

$$\Delta g(x, y, z) = g_{obs}(x, y, z) - g_{teoritis}(x, y, z) \tag{2}$$

where g(x, y, z) is the gravitational field anomaly in the topography, gobs (x, y, z) is the observational gravitational field in the topography, and the theoretical (x, y, z) is the theoretical gravity field in the topography [5].

In the gravity method, several data corrections are carried out, such as free air correction (FAC), field correction (TC), and Bouguer correction (BC) [2, 6]. Free air correction, the basis of this correction is that it is necessary to compensate for the decrease in the value of gravity caused by the farther distance from the geoid. The gravity measurements result at sea can be compared directly to the value of normal gravity by considering the geoid plane corresponds to sea level [13]. However, the gravity measurements on land must be subject to correction due to the altitude below or above sea level. In fact, the free-air correction is the overall gravity of the earth that can be considered equal if the mass is concentrated at its center. If the distance of the spheroid surface of the earth center is r and the height of the gravity measurement at the extreme point of the spheroidal plane is h (where h $\ll$ r), if g(r) represents gravity on the geoid plane or normal gravity, then the acceleration of gravity at that point is following the Taylor series. Terrain correction, Topographic conditions around the observation point are sometimes irregular, such as valleys or hills which also affect the acceleration of gravity at the observation point. The existence of a hill will have the effect of reducing the acceleration of gravity [11]. Therefore, the terrain correction for this hill must be added to the rock, which means that any valleys around the observation point are considered to have rock mass. [10]. Topographically, it is considered to be a concentric cylindrical shape which is divided into zones with compartments with different heights, and is written in the form of the formula

$$TC = 2\pi\gamma\upsilon\left[R_2 - R_1 + \sqrt{R_1^2 + \Delta h} - \sqrt{R_2^2 + \Delta h^2}\right] \tag{3}$$

where R_1 is the inner radius, in a zone, R_2 is the outer radius, in a zone, and then h is the height difference from the observation point.

According to the free air and normal gravity corrections, the rock mass between the point and the datum plane is neglected. However, in actual conditions, the mass below the point of measurement must be considered. Thus, in Bouguer's correction, the height

Fig. 1. The gravity data point of the research area

of the extreme point of the datum plane and the rock mass density between the extreme point and extreme plane must be calculated [14]. The Bouguer correction is the opposite of the free-air correction. It has to be subtracted if the point is very above the datum plane and it has to be added when the point is very below the datum plane.

In this study, the satellite gravity (TOPEX) pages were used as gravity data with the website address http://topex.ucsd.edu/cgi-bin/get_data. TOPEX Satellite observation data in the form of FAA (Free Air Anomaly), the gravimetric satellites have a basic concept in the detection of the earth's gravitational field change by monitoring the occurrence of changes in distance between the two pairs of gravimetric satellites in orbit [13, 14, 15]. The two satellites are traveling to each other on an orbital track with a distance from one satellite to the second satellite of about 220 km. The of gravimetric satellites accuracy is 1 cm for geoid height and one mGal for gravity anomaly on a spatial grid of 100 km on the earth's surface, even less. In this study, the authors used data from the TOPEX/Poseidon satellite**.** In Fig. 1, it can be seen that the red dot is the earthquake's epicenter, and the yellow dot is the data collection point of gravity**.**

3 Results and Discussion

In the last few years, there have been several earthquakes on the island of Kalimantan, and even some were destructive earthquakes. As happened on March 1, 2022, the epicenter was on land 46 km northwest of Paser (Fig. 1). According to data from the Metrology, Climatology and Geophysics Agency (BMKG), the earthquake had a hypocenter at a depth of 10 km and an epicenter 46 km northwest of Paser be felt on the MMI II-III scale. Based on BMKG information, the trigger for this earthquake was the Meratus Fault. This earthquake proves that the earthquake fault is still active after having caused a destructive earthquake on October 25 and 26, 1957, and then through the release of energy of magnitude 6.1. This means that the earthquake caused a disaster. The earthquake incident can at least answer that the island of Kalimantan is not entirely safe from earthquakes or other disasters. Research is needed to identify disaster risks, one of them by using geophysical methods. Geophysics is one of the sciences that study the earth using physical parameters. The geophysical method that can be used to describe the shape or subsurface geology is gravity method. The gravity method can describe the shape or subsurface geology based on variations in the earth's gravitational field owing to differences in density or mass density between rocks. One of the technologies that are considered efficient for this is to use TOPEX satellite gravity distribution. The Bouguer and terrain corrections that have gone through the adjustment of the range of values of the corrections have resulted in a map that is Complete Bouguer Anomaly (CBA) as shown in Fig. 2.

Figure 2 is a representative of the study area contour map of the complete Bouguer anomaly. The gravity method can be relied upon to investigate the structure of the subsurface in an area. The gravity method is environmentally friendly, it measures the variation in the acceleration of Earth's gravitational on the surface. The acceleration of gravity variation is owing to variations in the density of the rocks below the earth's surface. The gravity method is applied to the measurement of subsurface structures in the East Kalimantan area. The results of the measurement and data processing of variations in the acceleration of gravity of the earth in the investigation area provide an overview of

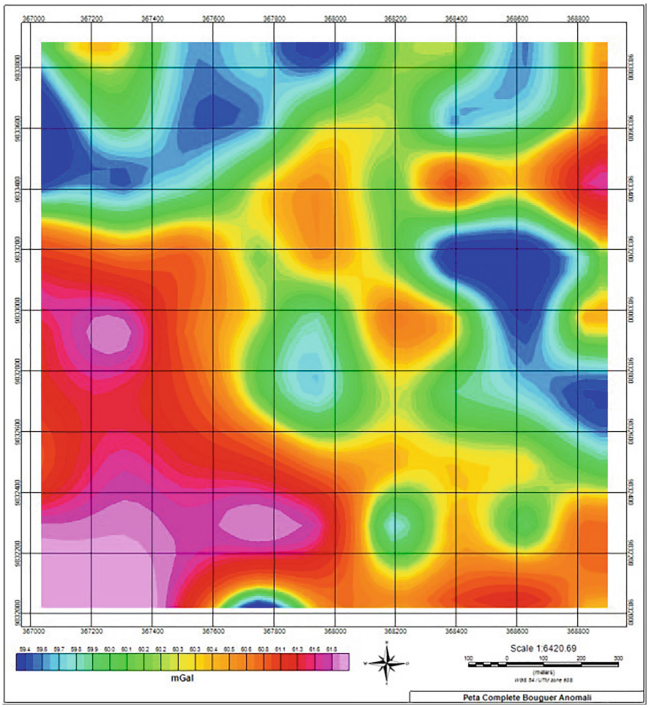

Fig. 2. Complete Bouguer Anomaly Map

the contours of the Bouguer anomaly (Fig. 2). Based on the distribution of the Bouguer anomaly, it can be seen that the distribution of the density variation values is in the range of 50 mgal to 60 mgal. On the CBA map, it can be interpreted that there is a change in anomaly, which can be seen from the density distribution based on the color of the map. The blue color is representative of low-density values and the purple color is representative of high-density values. The complete Bouguer anomaly was used in this study as a basis for modeling the gravity data inversion (Fig. 3).

An inversion modeling was used in this study based on the complete Bouguer anomaly with two sections. By orienting at the epicenter of the earthquake as a reference. With contrast density from −0.863 mgal to 0.932 mgal. The model shown is 3D from a CBA map. Based on the 3D model obtained, the distribution of the density value anomaly from the research area, the largest value from high to low can be seen. There are red and green colors as changes in the density anomaly value from the range of values of −0.391 mgal to 0.455 mgal. This indicates that there is an anomaly beneath the surface.

Figures 4 (a) and (b) show that high and low-density anomaly values can describe the existence of something under the structure. This allows for structural differences which indicate a local fault in the Paser area. The high anomaly values are scattered at the edge of the data collection area and the low-density anomaly values are in the middle of the data collection area.

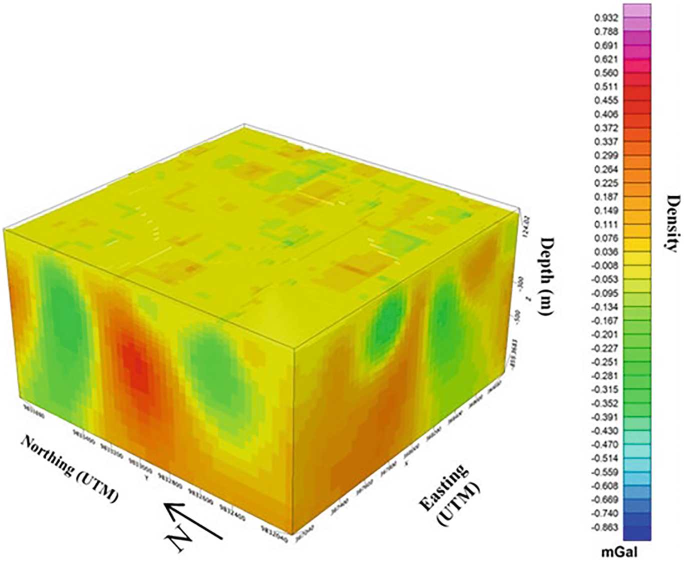

Fig. 3. Model of the inversion data of the research area

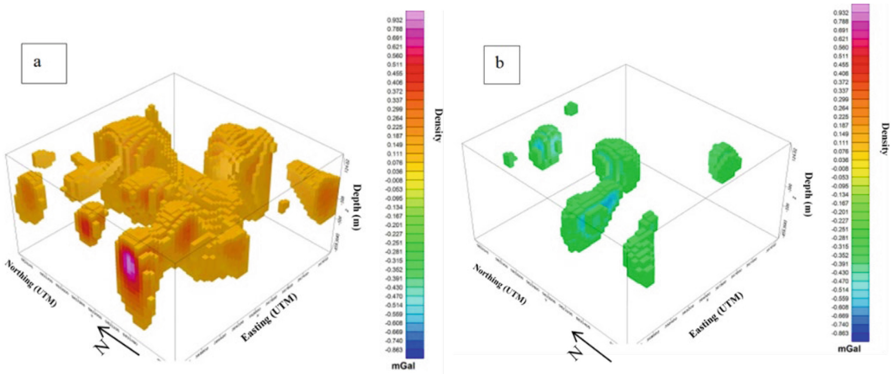

Fig. 4. High (a) and low (b) Density Models Facing the Southeast

4 Conclusion

In this paper, Based on the 3D model obtained, the distribution of the density value anomaly from the research area, the largest value from high to low, can be seen. Furthermore, there are red and green colors as changes in the density anomaly value from the range of values of −0.391 mgal to 0.455 mgal. This indicates that there is an anomaly beneath the surface. This allows for structural differences which indicate a local fault in the Paser area.

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