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Analysis of Formation Ronggojalu Spring and Probolinggo Active Fault Continuity with Satellite Data Gravity Method

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Abstract: The Ronggojalu spring, with a discharge intensity of more than 3,000L/second, makes it one of the spring with the most significant discharge in Indonesia and is the main supplier of clean water for the City of Probolinggo. From the observation of topographic maps, the existence of this spring forms a lineament with Paras Spring and Sumber Kramat with a direction of Northeast to Southwest. The presence of this lineament can indicate the existence of geological structures that play a role in the formation of spring. In addition, this lineament is in the same direction as the active Probolinggo fault identified by PUSGEN (Pusat Studi Gempa Nasional). This study aims to identify the presence of geological structures in the lineament using satellite gravity data GGMplus (Global Gravity Model) and Remote Sensing. This data is quite efficient and effective in identifying subsurface geological structures. With the SVD (Second Vertical Derivative) analysis, the residual anomaly results from the second derivative value of the Bouger anomaly so that it can show the density contrast value as an indication of the geological structure. From the results of the interpolation of satellite gravity data in the study area, the CBA (Complete Bouguer Anomaly) value range is -16.8 – 4.8 mGal. The analysis of SVD and FHD shows a significant contrast different values along the fault line that passes through the spring. The lineament density processing also shows a weak zone around the fault zone, indicating the continuity in that zone. The existence of a fault under this spring indicates the influence of the fault on the formation of Ronggojalu Spring, Paras Spring, and Keramat Spring. In addition, it is estimated that this fault is a continuation of the active Probolinggo fault.

Keywords: faults; gravity satellites; lineaments; spring; SVD.

Introduction

Ronggojalu spring is a hydrogeological phenomenon located in the Tegalsiwalan District, Probolinggo Regency. The spring that appears by itself has a large debt of around 3,000 L/second and is one of the clean water sources for all residents in Probolinggo (Silvia & Arlini, 2021). The needs of clean water can increase over the years and corresponding to the increase of population. Ronggojalu is located in an area with sloping topography and is not close to the mountains where most springs appear. In addition to Ronggojalu, there are two other springs that create a lineament with Ronggojalu, namely Sumber Paras and Sumber Keramat, which appear with the large flow. The three springs arise due to the presence of subsurface structures indicated by the lineament of the springs. This study aims to identify the presence of geological structures in the lineament using satellite gravity data GGMplus (Global Gravity Model) and Remote Sensing

Based on the regional geology of Probolinggo in figure 1, the Ronggojalu spring is located in alluvium with lithology composed of clay, mud, sand, pebble, cobble, and boulder (Suwarti & Suharsono, 1992). Considering the lineament, this indicates that the springs did not appear due to the presence of lava or

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changes in the local topography but occurred due to the subsurface structures. This structure is associated with the Probolinggo fault, which extends Northeast to Southwest from Argopuro Volcano, indicating that the fault moves horizontally (PUSGEN, 2017). The relationship between the springs and the geological structure below the surface is crucial as it intersects impermeable zone and confined aquifer zone (Fajar et al., 2021). The geological structure resulting from a fault can create secondary structures such as fractures, Fractures can transform areas from impermeable zones to permeable zones, as the porosity of the fractured zone in lithified sediments allows water to pass through (Bense et al., 2013).

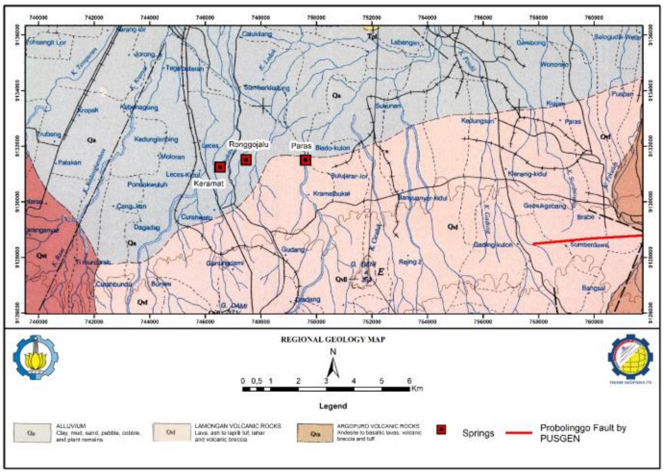


Figure 1. Regional geological map of the study area of spring lineage with its relationship to the Probolinggo fault (Suwarti & Suharsono, 1992)

The gravity method is one of the best geophysical methods for obtaining subsurface results, especially in identifying fault structures (Chen, 2015). The gravity method is a method that measures the value of the Earth's gravitational field caused by the influence of subsurface density variatons (Hinze et al., 2013). First Horizontal Derivative (FHD) and Second Vertical Derivative (SVD) are used to identify subsurface geological structures because these methods are derived from the Bouger anomaly, which can show shallow anomaly effects (Blakely, 1995). The fault zone area can also be determined using the Remote Sensing method based on the lineamanent density of the research area. Areas with high lineament density indicate many joints or fractures, thus indicating a weak zone of fault structure (Zaenudin et al., 2021).

Method

This study used satellite gravity data taken from GGMplus 2013 with a research area of 25 km x 10 km, as many as 5.357 points with a distance between points of 200 m. Gravity data from GGMplus 2013 is used because GGMplus has better accuracy, where GGMPlus is claimed to be able to detect the value of the observed gravity and geoid undulation values with data density intervals ranging from 200 - 300 meters from latitude 60° north to 60° south latitude (Hirt et al., 2013). Satellite image data is processed using DEMNAS data with accuracy of up to 8m which was built from several data sources, including IFSAR data (5m resolution), TERRASAR-X (5m resolution) and ALOS PALSAR (11.25 m resolution), by adding Masspoint data resulting from stereo-plotting (BIG, 2023;Nugroho,2023).

By doing several corrections in Gravity data processing is obtained the CBA (Complete Bouguer Anomaly) value through, assuming that the density value of the research area is the same as the density of the continental crust (2.67 g/cc) (Hameed, 2023). Through the concept of the FHD (First Horizontal Derivative) and SVD (Second Vertical Derivative) methods, it will be able to show the results of the interpretation of the fault structure, where the results of the slicing through the fault will show the contrast of values that occur between a peak derivative of the Gravity anomaly value indicating differences in structural patterns and interpretation of depth deposition of sediment or pyroclastic (Aziz et al., 2018; Rosid & Siregar, 2017)

Remote sensing processing consist lineament extraction from Digital Elevation Model (DEM) data processed in Hillshade form. Lineament extraction is processed with the number and length of the extracted line depending on the value of an optional digit from LINE modulus as the input parameter in the PCI geomatica software. This modular algorithm consists of three stages: edge detection, thresholding and curve extraction (Marzougui, 2020). However, the LINE module extracts the lineament from the image and converts these linear features in vector form using the six optional parameters RADI (Radius of filter in filter), GTHR (Threshold for edge gradient), LTHR ((Threshold for curve length), FTHR (Threshold for curve length), ATHR (Threshold for angular difference), and DTHR (Threshold for angular difference) (Sarp, 2005; Ranjbari, 2023).

Result and Discussion

After several corrections such as Terrain Correction, Free Air correction, and Bouger correction, the results of the Bouger anomaly value distribution in the study area are shown in Figure 2. The results of the CBA shows the range of anomaly values in the area was -16.87 to 4.85 mGal. At the springs location, Bouguer anomaly range from -12 to -8 mGal. In contrast, Bouger anomaly is more positive in the Probolinggo fault area. The difference in the anomaly value is due to differences in the rock density from the lithology of the study area and the presence of subsurface structures.

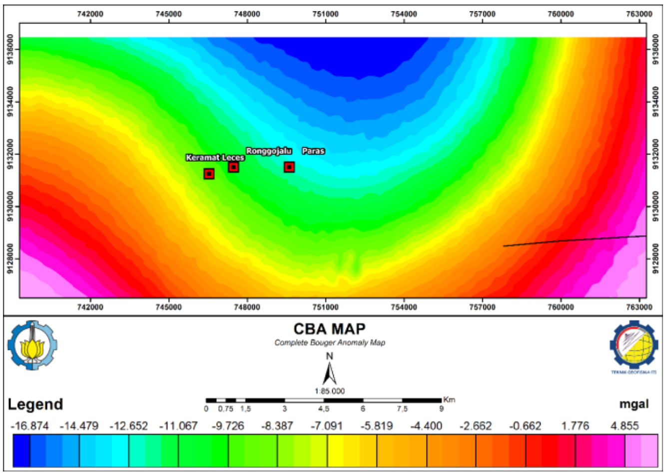
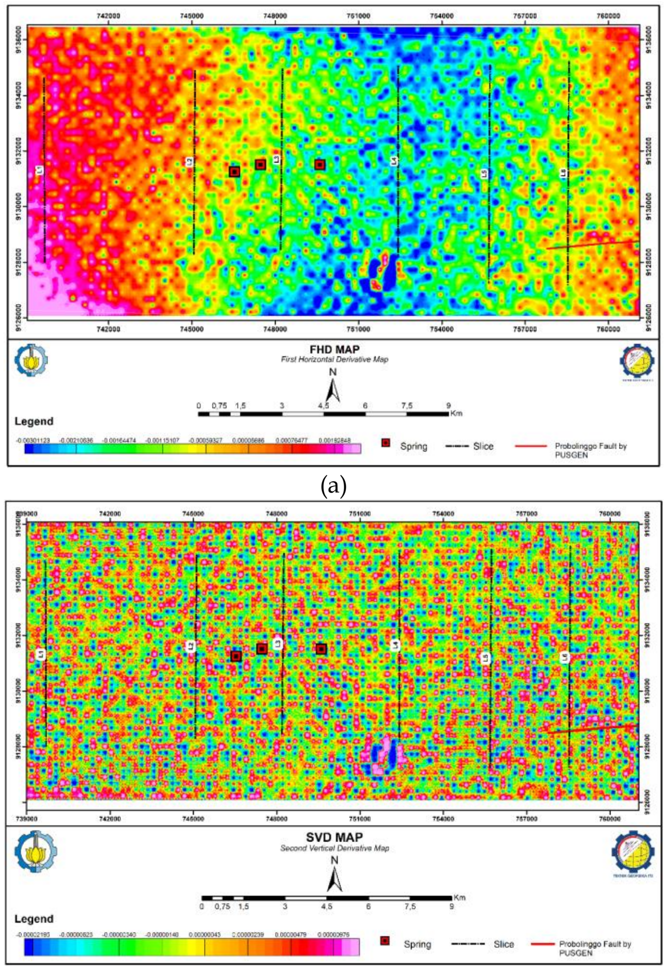


Figure 2. Map of the distribution of CBA values in the research area

Using the CBA results, the FHD and SVD analysis processes are carried out to determine the point of continuity of the fault that passes through these springs. The analysis of the determination of the fault point was carried out with 6 slicing that passed through the springs point and some of the known faults. The slice results in Figure 3 shows graphic of the SVD and FHD values in the slicing that indicate the location of the fault. The determination of the point will be known from the difference in the value of the graph that changes instantly. The analysis of SVD and FHD graph in Figure 4 found the continuity of the Probolinggo fault passed through the springs. All the slicing on the FHD graph shows a significant contrast difference value, marked by the black line, indicating that is an area where there is a fault. Meanwhile, the SVD graph also shows a difference in contrasting values where the point of continuity from the Probolinggo fault that passes through the springs. The analysis of SVD can show the type of fault with SVD anomaly value (+) have greater than SVD anomaly value (-), so that the fault can indicate as normal fault (Sastranegara et al., 2015).



(a)

(b)

Figure 3. Anomaly distribution map with slicing to determine the point of continuity of the fault (a) FHD map (b) SVD map

Figure 5 shows that the continuity from the Probolinggo fault that leads to E – W changes its direction to SE-NW, which passes through the three springs. The indication is determined based on the interpretation of gravity data through the processed SVD and FHD methods. So it is very likely that the lineament of the three springs (Ronggojalu, Paras, Keramat) is caused by the continuity of the Probolinggo Fault. The emergence of springs can be estimated because of the fault structure in the area.

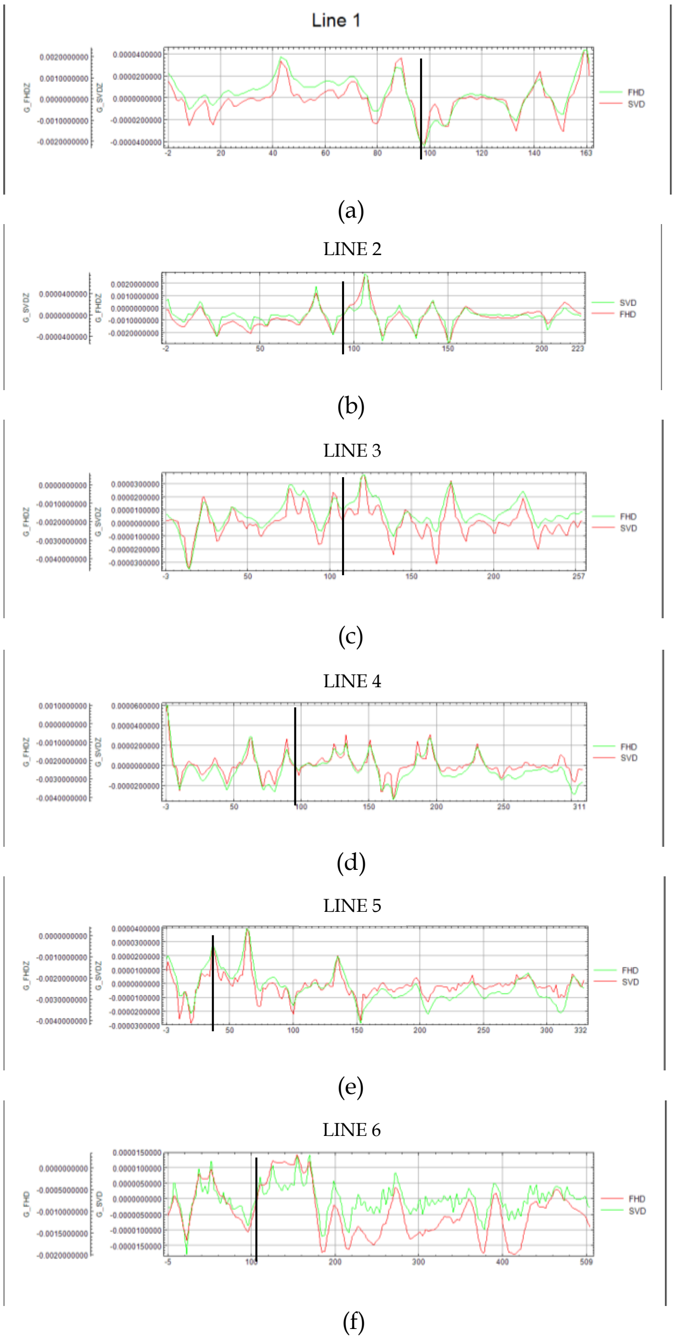


Figure 4. FHD and SVD slicing graphics a) Line 1 b) Line 2 c) Line 3 d) Line 4 e) Line 5 f) Line 6

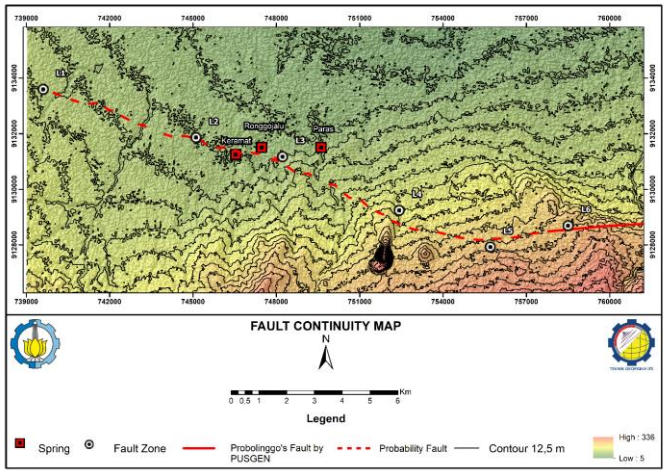


Figure 5. Map of fault continuity

The results of lineament density processing in Figure 6 shows a distribution of areas with a large lineament density in the west and east of the research area. In contrast, the middle area has less lineament density. This is due to the western area has alluvial lithology prone to erosion that can cause lineament areas (Shekhar, 2015). For the eastern zone around the Argopuro Mountains, the lineament in the form of valleys cause the high lineament density in the area. By associating the fault zones, it is found that there are weak zones at the points indicating the continuity of the fault which are shown in areas with high lineament density, especially in the western spring area (Nugroho, 2016). Moreover, this may reinforce that the continuity of the Probolinggo fault heading towards the NW through the three springs. It is shown by the weak zones of lineament density due to the fault.

The fault structure causes a fracture that intersect water's impermeable zone and confined the aquifer zone so that there is room for water to rise through the fracture (Kodoatie, 2012). Based on this, a conceptual model was created, as shown in Figure 7a, which indicates that a normal fault, or geological structure below the surface, was responsible for the formation of three large springs.

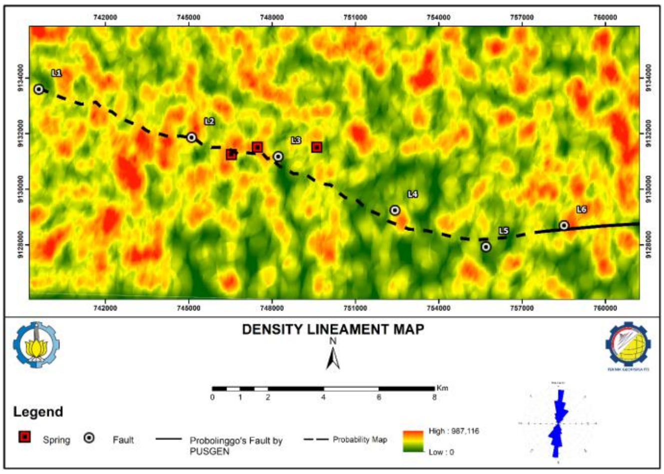
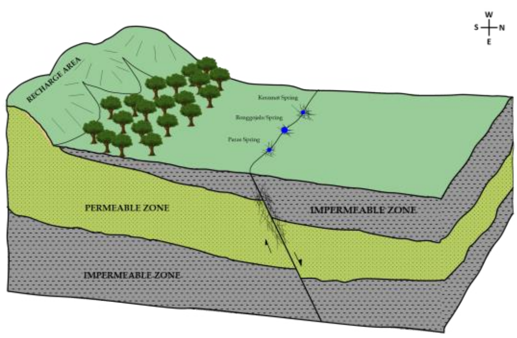
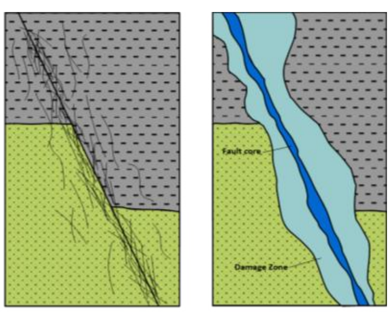


Figure 6. Fault lineament density map

The formation of a normal fault can result in secondary structures, such as fractures and is always surrounded around fault core (Choi, 2016). The zone of fractures, known as the damage zone, typically increases the permeability of the rock and enhances fluid flow due to the increase in porosity created by the fractures. (Keegan-Treloar et al., 2022). This situation can cause water in the permeable zone to fill the porosity of the damage zone and fault core, and flow to the surface (Cook, 2006). Therefore, the large debit flow of the three springs is likely due to the numerous fractures in the subsurface resulting from the fault



a)



b)

Figure 7. a) A conceptual model demonstrates that normal faults can cause the formation of three springs and secondary structures (fractures) b) Faults and fractures create big porosity, allowing water from permeable zones to fill in these voids and flow as a fluid. *Modified from* (Bense et al., 2013)

Conclusion

Based on the results of this study, the Gravity data processing found that there was a continuous anomaly from the Probolinggo fault passing through the three springs so it found the presence of subsurface structure continuation in Ronggojalu Spring that is a clean water source in Probolinggo. The analysis of FHD and SVD graphs shows an anomaly in the form of a fault geological structure that extends in the Southeast – Northwest direction. In addition, the lineament density method found that there are weak zones located at the point of fault continuity and near springs. These two methods indicate that the formation of the three springs is related to the geological structure of the Probolinggo Fault. Therefore, these spring are included in the structural spring

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Author Contributions
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Conflicts of Interest
The authors declare no conflict of interest.

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