Hindawi
International Journal of Geophysics
Volume 2022, Article ID 9737979, 13 pages
https://doi.org/10.1155/2022/9737979

Research Article

Gravity and Remote Sensing Methods as a Solution in Identifying Geothermal Reservoirs on Volcanoes

Wiyono,[1] **Salman Hamja Siombone**,[2] **and Sukir Maryanto**[1]

[1]*Department of Physics, University of Brawijaya Malang, 65145, Indonesia*
[2]*STKIP Gotong Royong Masohi, Maluku 97514, Indonesia*

Correspondence should be addressed to Wiyono; wiyonogeofis@ub.ac.id

Received 27 June 2022; Accepted 17 August 2022; Published 13 September 2022

Academic Editor: Muhammad Tayyab Naseer

Tiris Village, Lamongan Volcano complex is an area that has geothermal potential. The existence of geothermal potential in this study was identified using the gravity method combined with remote sensing methods. Remote sensing method is used to obtain a map of the distribution pattern of the soil surface temperature and a map of the continuity of the straightness and fault structure. The data used in the remote sensing method is secondary data in the form of *Landsat*-8 imagery and *DEM SRTM* 1 arc. Processing of the soil surface temperature map was obtained by using *thermal infrared* processing *NDVI*. The form of continuity of the straightness or fault structure is obtained by processing *Landsat*-8 multispectral image data in the form of 567 band composite and *DEM SRTM data* form of 3D topographic modeling. The data from the composite band 567 was reviewed visually using a 3D topographic model. The gravity method is the main method in this research because it is used to obtain the residual Bouguer anomaly distribution. The residual Bouguer anomaly data was obtained by using the *moving average* through spectrum analysis. The residual Bouguer anomaly distribution can be used for qualitative interpretation of the distribution of the earth's gravitational acceleration at the measurement location. The quantitative interpretation of the gravity data is based on the surface density estimation graph using the Parasnis method and 3D inversion modeling, using residual Bouguer anomaly data. The results of 3D inversion modeling provide four types of subsurface rock layers based on the density distribution value, namely, the first rock layer $\rho_1 = 2.52 - 2.67\,\mathrm{g/cm^3}$, the second rock layer $\rho_2 = 2.72 - 2.77\,\mathrm{g/cm^3}$, the third rock layer $\rho_3 = 2.80 - 2.83\,\mathrm{g/cm^3}$, and the fourth rock layer $\rho_4 = 2.84 - 2.86\,\mathrm{g/cm^3}$. The third rock layer is assumed to be reservoir rock and is estimated to be at a depth of 500–800 meters below the measurement point. The fourth rock layer is assumed to be intrusive igneous rock, which penetrates dominantly in the middle of the measurement location, which is oriented southwest, south to north, which is indicated by the high anomaly continuity on the regional Bouguer anomaly map. Based on the results of 3D inversion modeling and spectrum analysis of the average depth of the regional Bouguer anomaly, it is found that the intrusive rock layer is thought to be at a depth of 350 meters below the measurement point.

1. Introduction

Indonesia is one of the countries with enormous geothermal potential globally [1]. Based on the latest survey by the Geological Agency, Ministry of Energy, and Mineral Resources, it is known that Indonesia's total geothermal potential is 28,579 MWe. However, its utilization has only reached 1,698.5 MWe (±9.3%) of the total geothermal reserves that have been in production [1, 2]. One of the provinces in Indonesia with significant geothermal potential is East Java, which is estimated to have a total potential of 1,140 MWe, which has been identified in 14 geothermal locations and is not yet operational, with survey status to the determination of mining working areas (WKP) [3, 4].

One of the locations in East Java Province that has the potential to have geothermal energy is Tiris Village, Lamongan Volcano complex, Probolinggo Regency [5]. Based on a survey conducted by Hitay Rawas Company regarding geothermal potential in Tiris, the geothermal power was found to be 147 MWe [3]. Meanwhile, the estimated reserves around Lamongan Volcano extend to the south and southwest with about 11 km^2 based on calculations using the

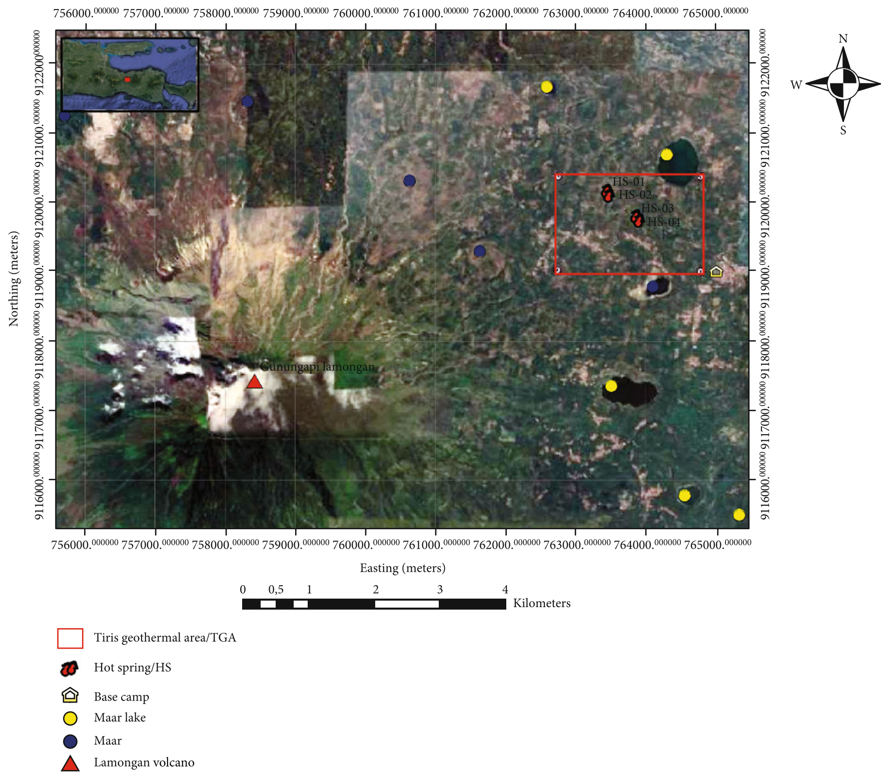


Figure 1: Research location map.

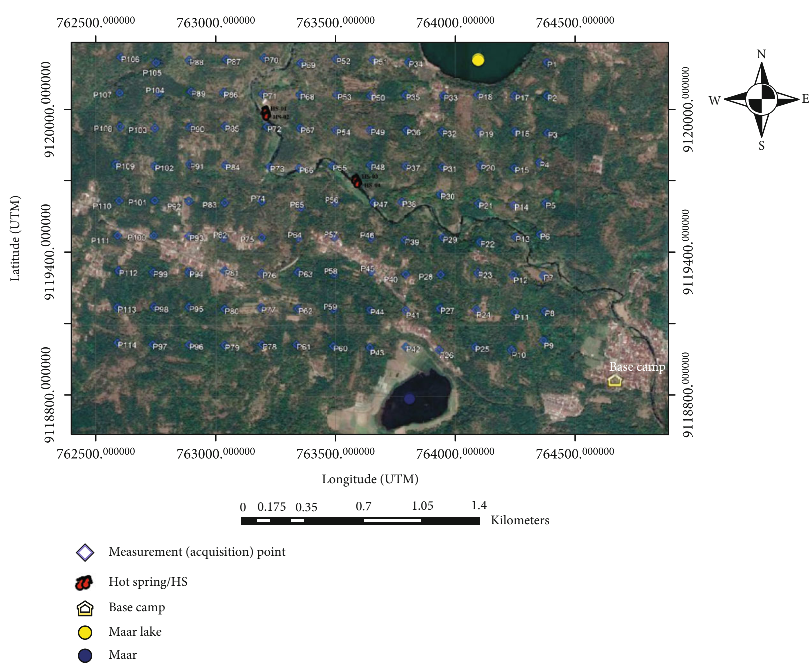


Figure 2: Google Earth-based gravity acquisitions map.

Monte Carlo method which is 74 MWe [6]. The geological structure that develops in the Tiris area is in the form of joints and faults. These faults are formed in Argopuro andesitic lava, Lamongan lava, and morphological lineaments in Argopuro pyroclastic flows. The presence of faults in this area is a hot spring path for hot fluids to reach the surface, thus affecting the alteration pattern and the emergence of hot springs [7].

The existence of geothermal manifestations in Tiris Village needs to be investigated in more detail to obtain certainty regarding the subsurface structure and an even description of the distribution of geothermal potential in this

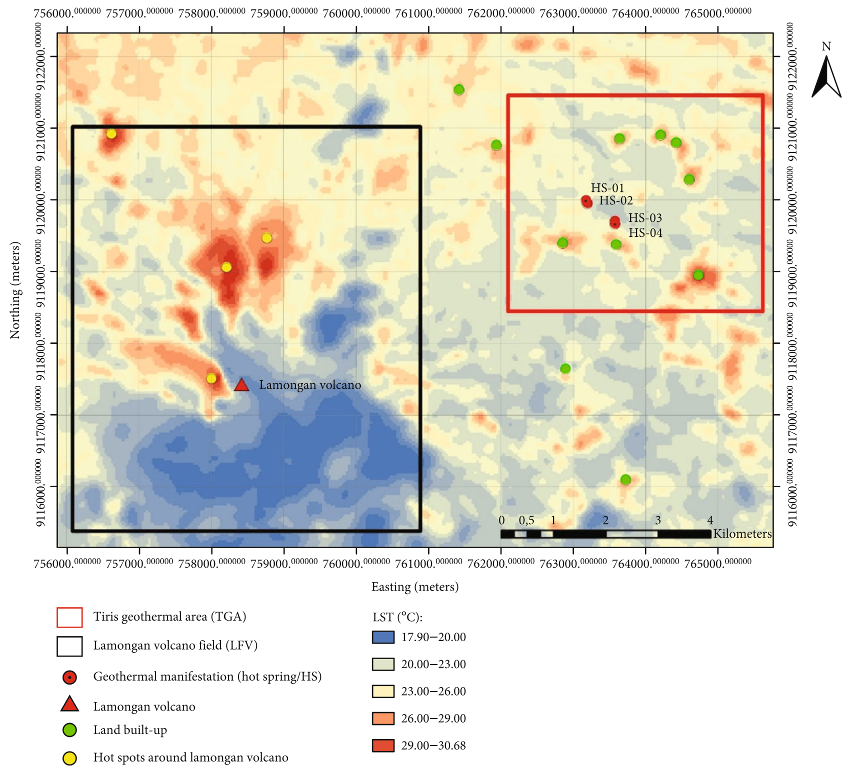


FIGURE 3: Estimation of LST from satellite coverage for the Tiris geothermal area of the Lamongan Volcano complex.

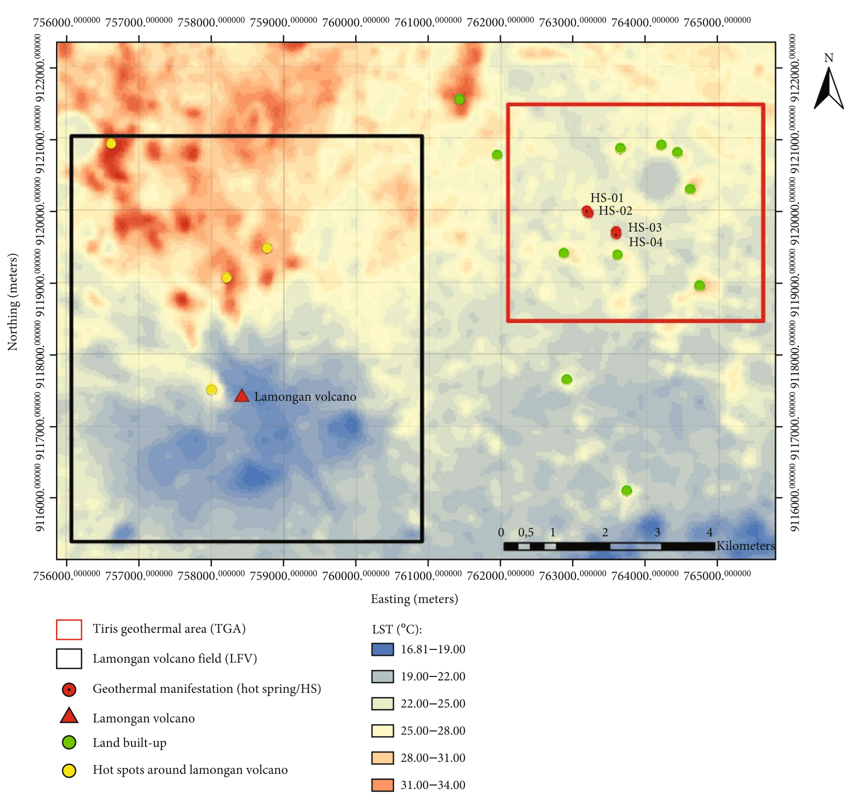


FIGURE 4: Estimation of ESG results from satellite coverage for the Tiris geothermal area of the Lamongan Volcano complex.

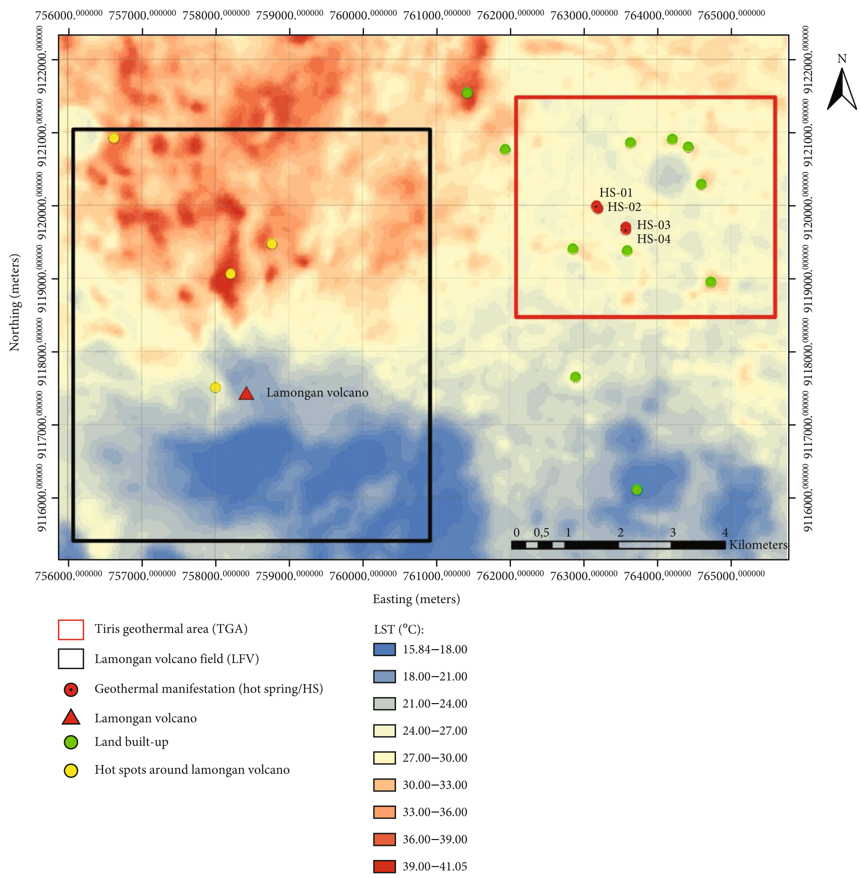


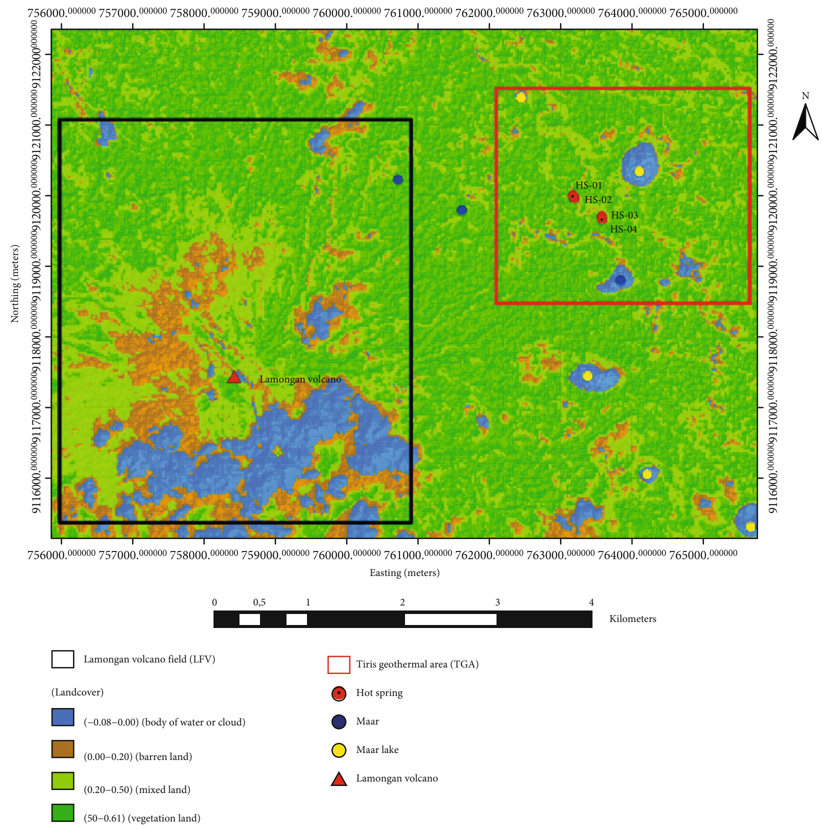
Figure 5: Estimation of ESG results from satellite coverage for the Tiris geothermal area of the Lamongan Volcano complex.

Figure 6: Hot springs on the banks of the Tancak. Watershed (DAS).

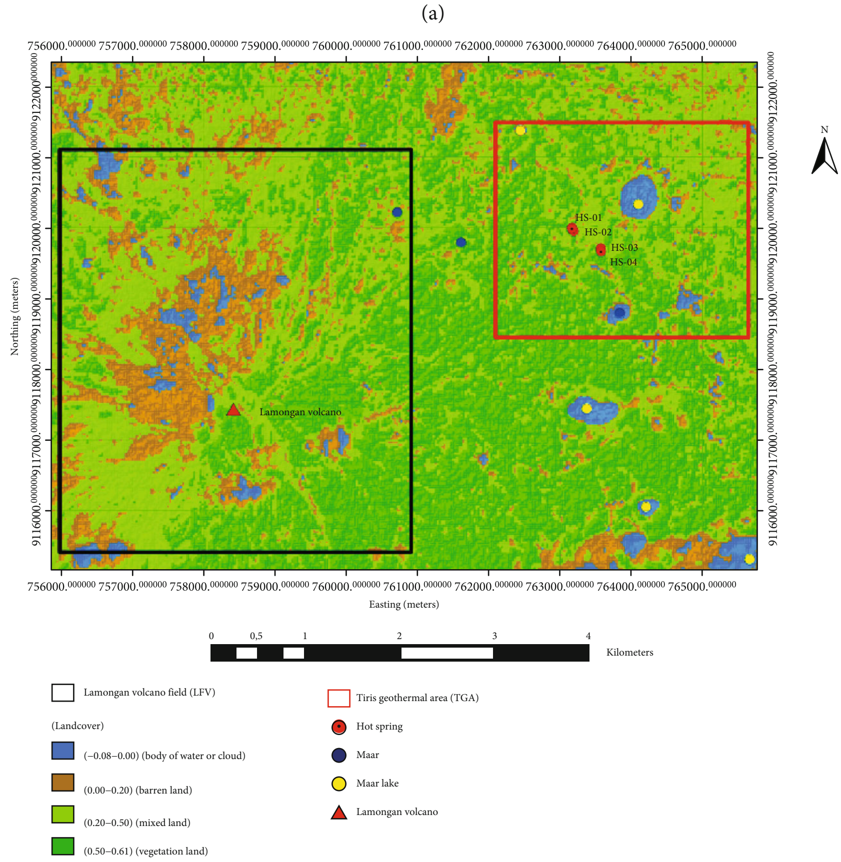
area [8]. The method that can be used in estimating the subsurface structure and the distribution of geothermal potential is by using the gravity method [9]. The gravity method is a geophysical method that measures variations in the gravitational field of a place on the earth's surface to obtain information in the form of the local density of a rock formation [10].

A preliminary study using the gravity method has been carried out [11] in Tiris Village, which includes geothermal manifestations around the Tancak river (northeast of Lamongan Volcano) with a distance between the acquisition points of 50-100 m. The research only focused on a not-so-wide area with an uneven distribution of acquisition points, where there were many blank spots. Hence, the distribution of geothermal potential in the research area was not fully captured. In addition, this research is only oriented to estimate subsurface rock types, so it cannot provide clear information regarding the presence of fault structures that control geothermal manifestations in Tiris Village. Based on these problems, it is necessary to carry out further research that focuses on areas that are suspected of having geothermal potential with a broader coverage area and an even distribution of acquisition points so that the results can describe the detailed subsurface structure of the research area including the presence of faults and geothermal reservoirs [12].

Geological structures in the form of faults that cut reservoirs can cause hot fluids to come out to the surface in geothermal manifestations [13]. In the Tiris geothermal potential area, there are two dominant faults: the straight

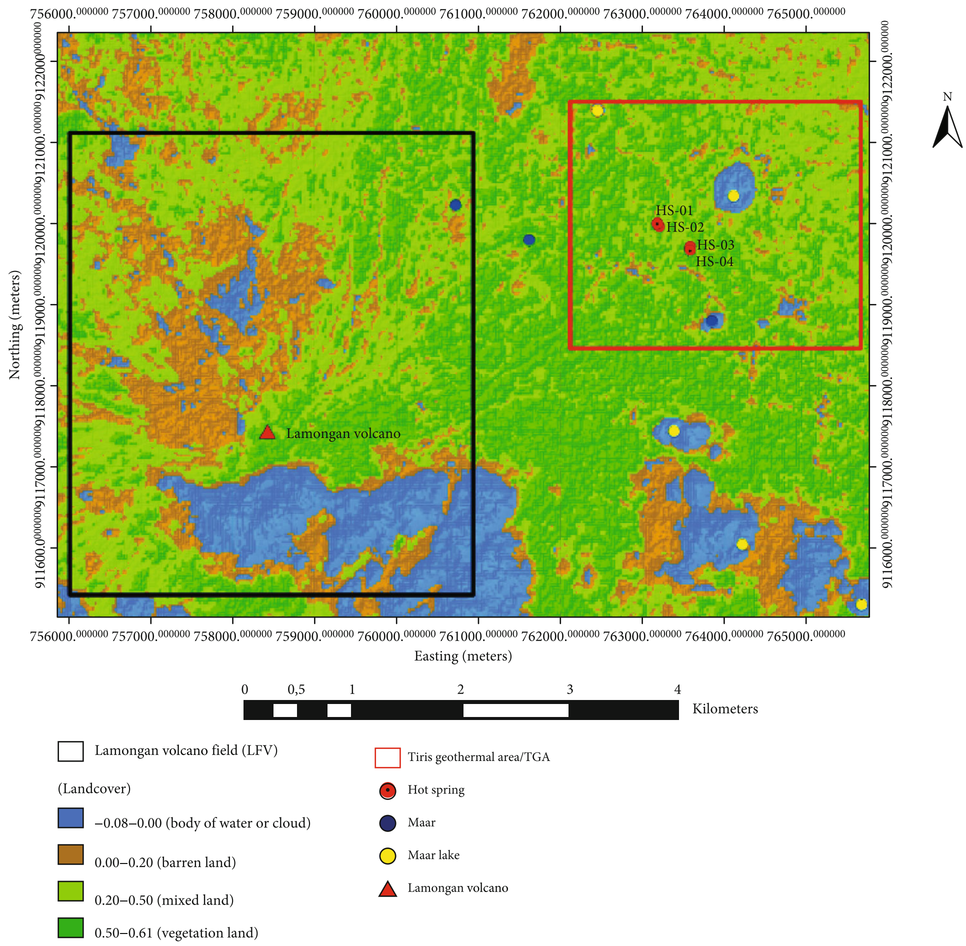


(a)



(b)

FIGURE 7: Continued.



(c)

Figure 7: NDVI at research locations with different coverage times: (a) May 07, 2018. (b) September 28, 2018, and October 30, 2018.

line structure of the Lamongan Volcano and the fault structure associated with the Tancak river, Tiris village [14]. The geomorphological order in the form of faults and the distribution of ground surface temperature, which indicates the presence of geothermal manifestations on the surface, can be investigated using remote sensing methods. Remote sensing is the science of obtaining information on objects through analysis and interpretation without touching the object directly [15]. Remote sensing methods will be very effective when mapping locations around Lamongan Volcano, an area with geothermal potential because field monitoring can be carried out without direct observation [16].

Previous research using the Landsat-7 remote sensing method [14] has been carried out to map the geomorphology and distribution of soil surface temperature in the Tiris geothermal potential area, Probolinggo. This research has not shown precise results related to geomorphological appearances in the form of faults and the distribution of soil surface temperatures in the Tiris Village, Lamongan Volcano complex. Landsat-7 has several weaknesses. Namely, it has a low spectral resolution, radiometric performance, and low SNR (signal to noise ratio) compared to the latest Landsat release, namely, Landsat-8. Landsat-8 thermal band processing results will produce a temperature anomaly indicating the presence of geothermal manifestations [14]. The data from Landsat-8 image processing can be used to support the interpretation of the Bouguer anomaly data (primary data) in the study.

This study is aimed at determining the distribution of ground surface temperature based on remote sensing data analysis, determining the appearance of lineaments and faults in geothermal areas based on remote sensing data analysis, and determining the description of the position of geothermal reservoirs in the geothermal area of Tiris village, Lamongan Volcano complex, Probolinggo Regency, East Java, based on Bouguer anomaly data.

2. Materials and Methods

This study's location for measuring gravity data was carried out in Tiris Village, Lamongan Volcano complex, Tiris District, Probolinggo Regency, East Java Province. The location of the gravity data measurement is indicated by the area in the red box in Figure 1.

Gravitymeter LaCoste & Romberg type G-1053 acquisition devices were used to conduct gravity measurements in Tiris on 55 acquisition stations (Figure 2). The calibration factor of the tool can be used to measure all data acquisition

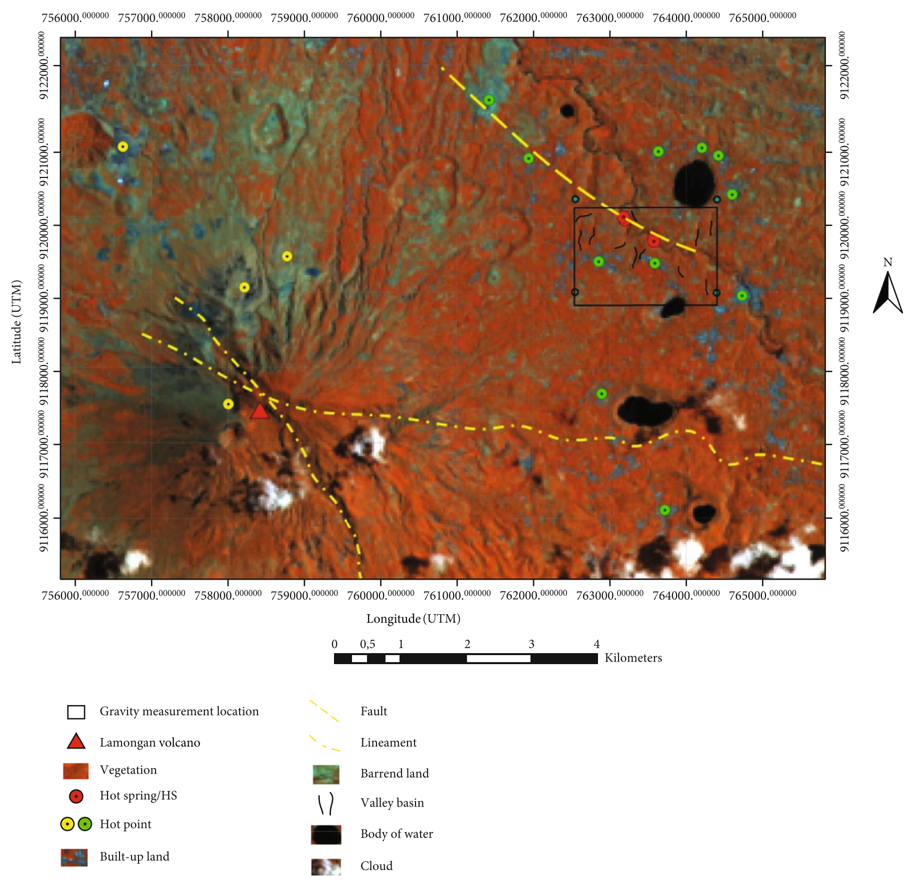


Figure 8: Map of composite results of Band 567 geothermal area of the Lamongan Volcano complex Tiris.

faults in a gravitymeter of type G-1053's mechanical design. In the meantime, there were 100 m between each of the survey's acquisition stations. The first derived connective point in the Physics Building of Brawijaya University Malang was tied to the field's base point.

Prior to applying corrections, the field-measured gravity data was first transformed into the miliGal gravity unit. Tidal adjustment, drift correction, gravity correction due to normal gravity, free air correction, Bouguer correction, and terrain correction were among the corrections. To eliminate the unknown components that exist below the surface and affect the value of gravity in order to acquire the gravity anomaly value, various data corrections were carried out (Bouguer anomaly). The difference between the observed gravity value and the theoretical gravity value in a certain reference plane at a measurement point is known as the Bouguer anomaly. This anomaly is caused by the nonhomogeneous inner density of the earth [17], and the anomaly value is calculated using the formula given below [10, 18]:

$$\Delta g = g_{\text{obs}} - g_{\varnothing\text{corected}},$$
$$g_{\varnothing\text{corected}} = g_{\varnothing} - \text{FAC} + \text{BC} - \text{TC}. \tag{1}$$

Hence, the following is obtained:

$$\Delta g = g_{\text{obs}} - g_{\varnothing} + \text{FAC} - \text{BC} + \text{TC}, \tag{2}$$

where Δg is the complete Bouguer anomaly (mGal), gobs is the accidents of gravity corrected with tidal and drift (mGal), $g\varphi$ is the normal gravity value at the point of measurement (mGal), FAC is free air correction (mGal), BC is Bouguer correction (mGal), and TC are Terrain correction (mGal). Normal gravity correction ($g\phi$), FAC, BC, and TC are theoretical values of gravity [18].

The obtained complete Bouguer anomaly values were still at their respective topographic heights before being projected into a plane at the same height. This projection result was used as the initial data for the upward continuity process, which was used to separate the entire Bouguer anomaly into regional and residual anomalies. Isostatic compensation based on regional topographic loads that can be correlated with the presence of basement is referred to as regional anomaly. Meanwhile, residual anomaly has been linked to shallower geological structures [18, 19]. As a result, estimating the geothermal reservoir structure of Tiris village requires a quantitative and qualitative analysis of residual anomaly.

3. Results and Discussion

The results of remote sensing data processing show that the distribution of high land surface temperature (LST) anomalies is not visible around the location of geothermal manifestations (hot springs). This is because these hot springs appear on the banks of the Tancak river basin, thus allowing

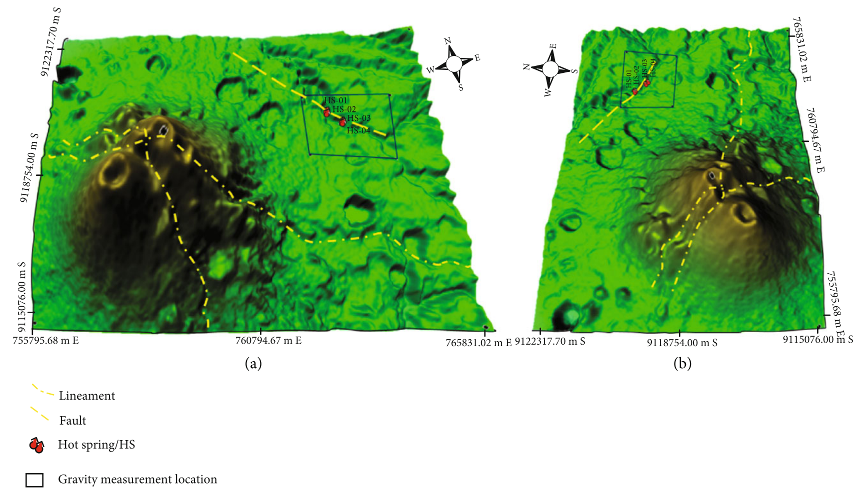


FIGURE 9: 3D visualization of DEM SRTM data. (a) 3D view of the research location from the south. (b) 3D view of the research location from the west.

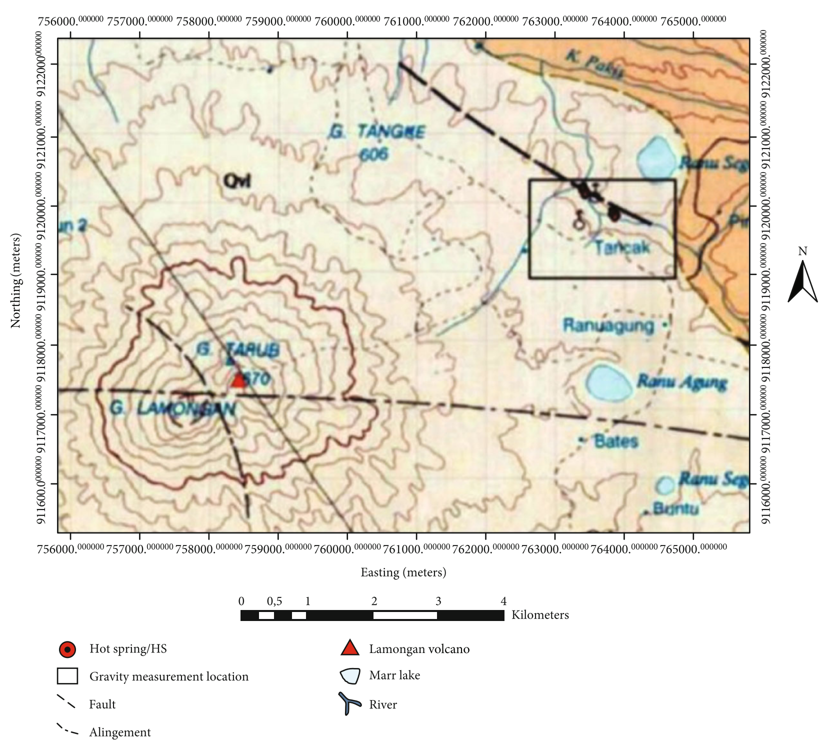


FIGURE 10: Geological map of research location sheet Probolinggo.

mixing between the temperatures of the springs. The heat and temperature of the river water flow can be seen in Figures 3–6.

Meanwhile, the distribution of land cover on the NDVI map in Figure 7 shows that the hot springs around the Tancak watershed are on mixed land. Based on the ESG map, it was found that the points with high ESG anomalies in the gravity measurement location (TGA area) are located in the built-up area, in the form of residential areas. Meanwhile, the points with high ESG anomalies spread to the north of the LVF area are in bare land locations filled with igneous rock in the form of pillow lava from the eruption

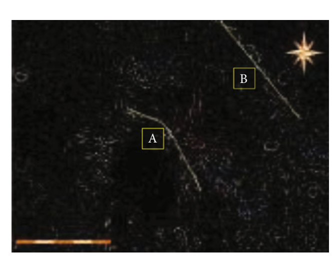


FIGURE 11: Geomorphological image of data processing band 4 in gray-scale format.

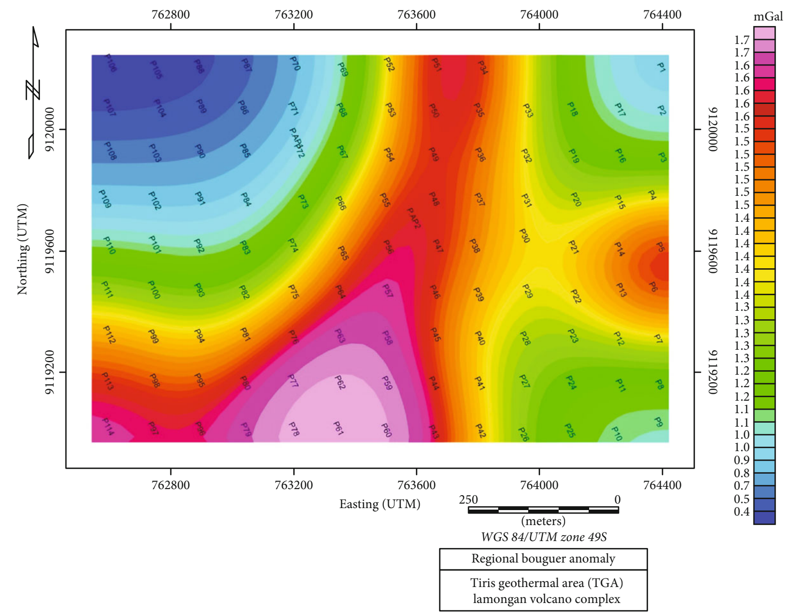


Figure 12: Regional Bouguer anomaly map at the measurement site.

of Mount Lamongan, so that they have a high thermal response to the Landsat-8 coverage image.

Based on the results of the correlation of the composite map of band 567 (Figure 8) and 3D DEM modeling (Figure 9) with the geological map (Figure 10), it is found that there is a similarity that there is a line structure in the body of Lamongan Volcano which is trending northwest-southeast and northwest-east. At the same time, to the northeast of Lmongan Volcano, precisely in the village of Tiris, there is a fault structure associated with the Tancak River Basin, which has a northwest-southeast direction. The existence of a straight line structure on the body of Lamongan Volcano and a fault structure in the geothermal area of Tiris village is strengthened by research conducted [14] using the single band method with a gray-scale display in band 4 Landsat-7, shown in Figure 11.

Based on Figure 11, the lineament structure of the body of the Lamongan Volcano is indicated by the letter A, while the fault structure in the Tiris geothermal area is indicated by the letter B. In addition, based on the data from gravity processing on the SVD anomaly map (Figure 12), it is found that the fault path in gravity measurement locations is trending northwest-southeast. This is consistent with remote sensing data, namely, the composite map of band 567 (Figure 8) and the 3D DEM model (Figure 9).

As seen in Figure 12, the location of the gravity measurement is in the Qvl rock formation (Quartenary Volcanic Lamongan), which consists of volcanic igneous rocks in the form of lapilli tuff, lahars, and volcanic activity breccias and lava (Suharsono & Suwarti, 1992). These rocks are igneous rocks resulting from the activity of the Lamongan Volcano. The average density of subsurface rocks at the measurement location was strengthened by the results of the surface density estimation using the Parasnis method, and the surface density value at the gravity measurement location was 2.72 g/cm^3 and the arrow image shows the fault

Figure 13: Massive rock outcrop at the gravity measurement location.

area. This condition indicates that the rocks that make up the subsurface at the gravity measurement location are composed of igneous rocks, which is indicated by the higher rock density values in the area. The high density of these rocks is reinforced by the many findings of massive igneous rock outcrops at the gravity measurement location (Figure 13).

Based on the 2D cross-section of the pie-cut results from the 3D inversion model (Figures 14 and 15), it can be seen that the subsurface conditions at the gravity measurement location consist of four rock layers. The four rock layers are lapilli tuff as topsoil, tufted tuffaceous breccia as cover rock, volcanic breccia rock as reservoir rock, and basalt rock as intrusion rock. The topsoil rock in this modeling is between 20 and 250 meters. The overburden is at a depth of 50 to 200 meters below the measurement point. Meanwhile, the reservoir rock is located 500 meters to 800 meters below the measurement point. It is estimated to be more dominant in the northwest direction, as indicated by the low residual Bouguer anomaly (Figure 16). The low residual Bouguer anomaly was formed due to a fault crossing the area, thus affecting the porosity of the subsurface rock due to the significant size discontinuity in the rock body. In addition, the position of the reservoir rock in this study cannot be appropriately studied because the measurement location is not so broad, and the distance between the measurement stations is so close that the description regarding the direction of the reservoir rock continuity has not been well captured.

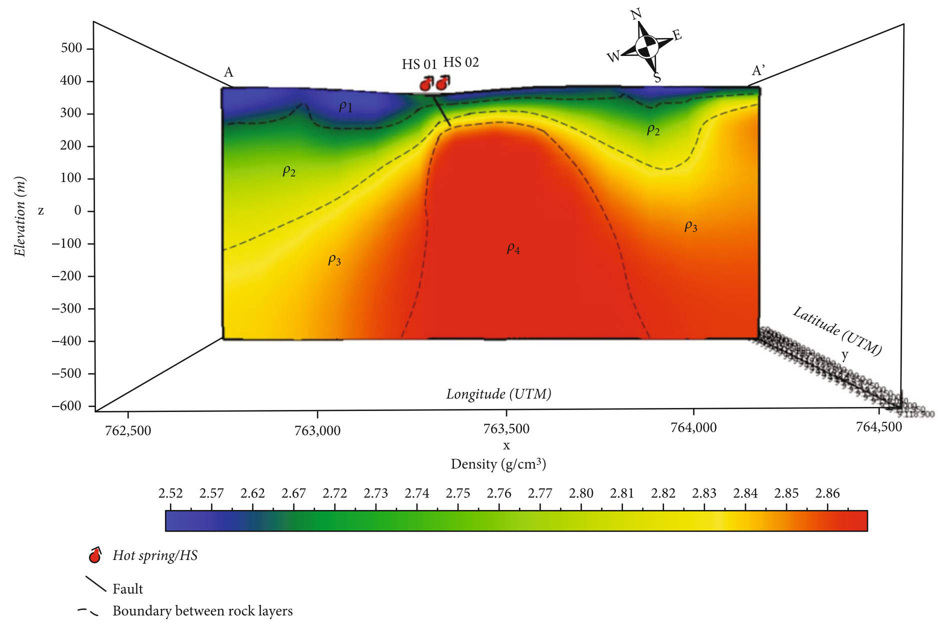


FIGURE 14: Cross-section of the A-A" incision on the body of the 3D inversion model.

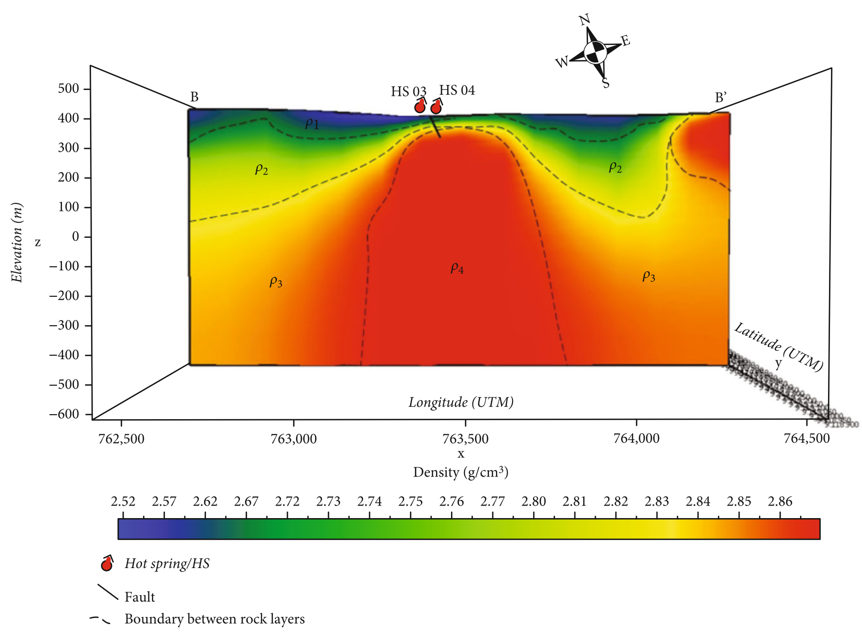


FIGURE 15: Cross-section of the B-B" incision on the body of the 3D inversion model.

Based on Figure 17, it can be seen that there is an intrusive rock in the middle of the body of the 3D inversion model from the gravity measurement location. The presence of intrusive rocks in the middle of the gravity measurement location can be indicated by the presence of a height anomaly in the middle of the gravity measurement location on the regional Bouguer anomaly map (Figure 12) and can be strengthened by the results of spectrum analysis; the average depth of the regional Bouguer anomaly is located at a depth of 348 meters below the measurement point.

The intrusion rock is thought to have originated from Lamongan Volcano because on the regional Bouguer anomaly map, the height anomaly is more prominent in the southwest-south direction, while Lamongan Volcano is on the southwest side of the gravity measurement location. In addition, in Figure 17, it can be seen that the slope of the fault is more inclined to the east at the measurement location. This is reinforced by the results of a geological survey (Ministry of Energy and Mineral Resources, 2017) that the slope of the fault is towards the Argopuro Volcano (Utama et al., 2012). A fault at the measurement location can be a channel way for hot fluid to move to the surface through weak zones around the fault (Ministry of Energy and Mineral Resources, 2017). The presence of these faults becomes a potential zone for fluids around the Tancak river path to move in (seep) towards the subsurface through rock

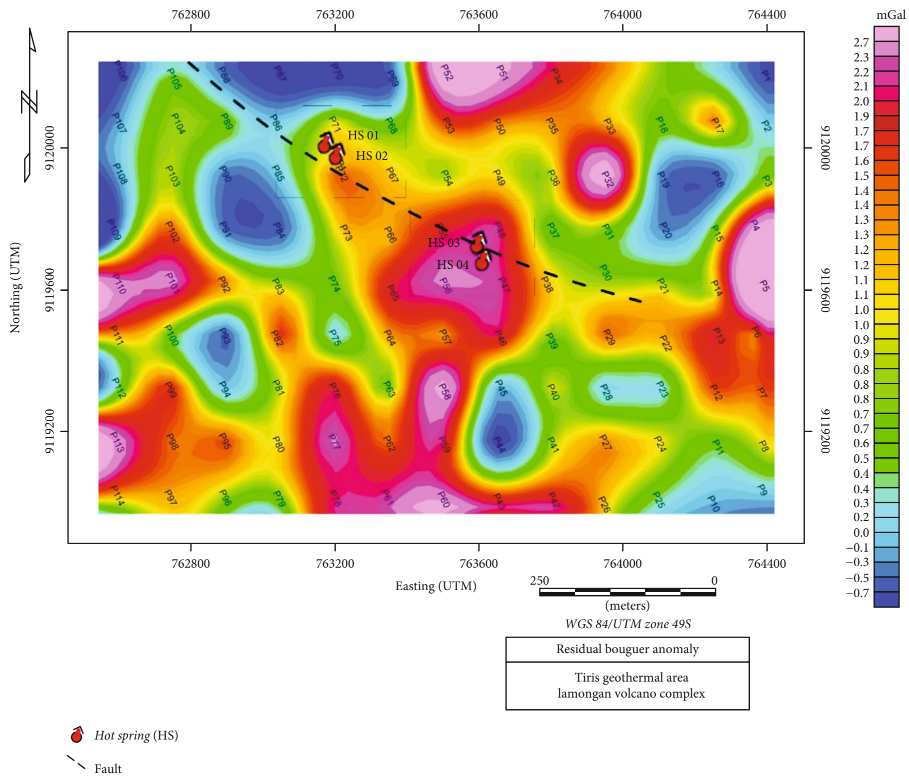


Figure 16: Map of residual Bouguer anomaly.

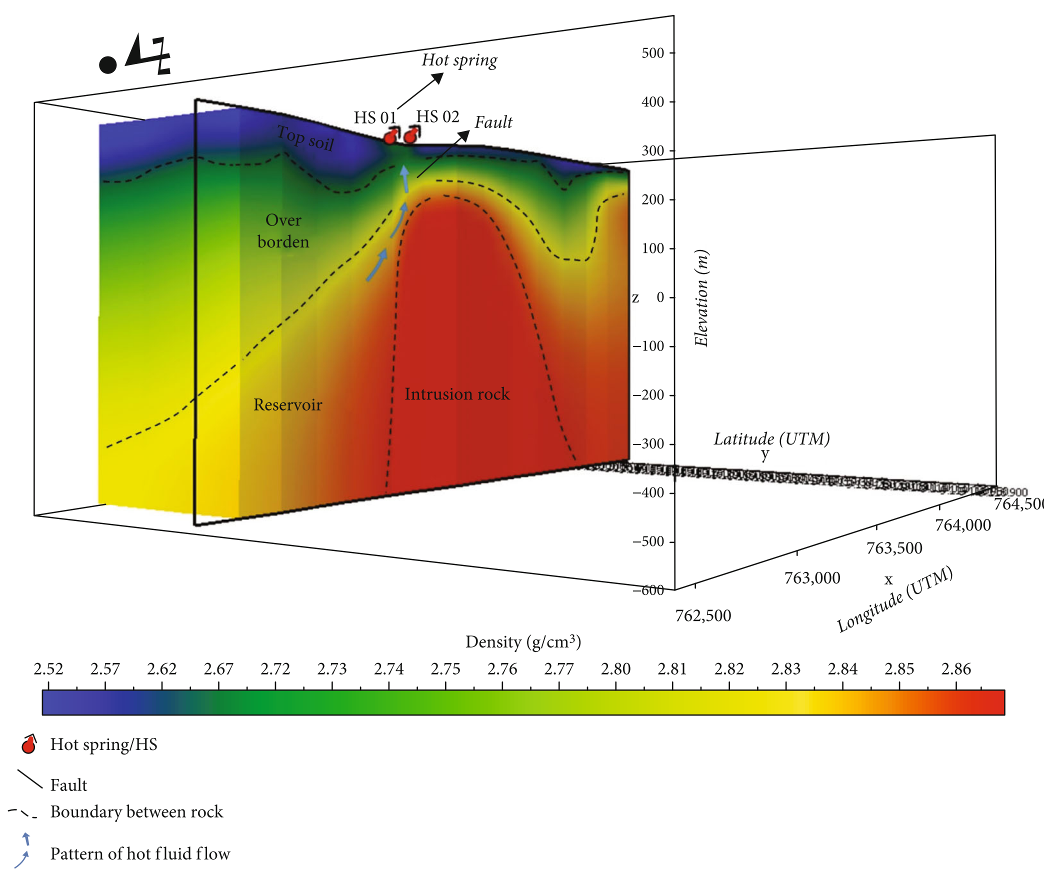


Figure 17: Conceptual form of subsurface conditions at the Tiris geothermal area.

fractures; then, the fluid is heated in the reservoir rock by heating rock around the reservoir rock. The heated fluid in the reservoir rock becomes lighter because its density decreases, along with the high reservoir rock temperature caused by the heating rock activity. The effect of high pressure on the rock walls of the reservoir triggers the hot fluid to move to the surface through the weak zones around the fault and form manifestations on the surface.

4. Conclusions

Based on the measurement results, the results obtained the distribution of ESG at the research location ranges from 15.84°C to 41.05°C, where there is a high ESG anomaly in the north of Lamongan Volcano due to the influence of cover changes, while at the location of the geothermal manifestation in Tiris village, there is no apparent LST anomaly due to the mixing between the temperature of the hot springs and the temperature of the water flow of the Tancak River. Then, there are two linear structures on the body of Lamongan Volcano, which are trending northwest-southeast and northwest-east, and there is a fault structure trending northwest-southeast to the northeast of Lamongan Volcano, which is associated with the Tancak river basin, Tiris village. Then, the rock suspected as geothermal reservoir rock at the gravity measurement location is volcanic breccia rock. This reservoir rock has a density ranging from 2.80 g/cm^3 to 2.83 g/cm^3 and is located at a depth of 500 meters to 800 meters in the sea, below the measurement point. The reservoir rock is more dominant in the northwest direction, indicated by a low anomaly on the residual Bouguer anomaly map.

Further research needs to be carried out using other geophysical methods, such as the magnetotelluric (MT) method, which has deep penetration and a high level of precision to determine the position of rocks, and it is advisable to conduct a geological study in the field to clarify the existence of lineaments and faults at the research site.

Data Availability

The [DATA.xls] data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

The author explains that the presentation of the manuscript is part of the thesis.

Conflicts of Interest

We have no conflicts of interest to disclose.

Acknowledgments

The author would like to thank profusely for the contribution of the Unit of Analysis and Measurement of the Department of FMIPA, LPPM Brawijaya University, Malang.

References

[1] E. S. D. M. Kementerian, *Potensi Panas Bumi Indonesia Jilid I*, Direktorat Panas Bumi, Direktorat Jenderal Energi Baru, Terbarukan dan Konservasi Energi, Kementerian Energi dan Sumber Daya Mineral, Jakarta, 2017.

[2] N. A. Pambudi, "Geothermal power generation in Indonesia, a country within the ring of fire: current status, future development and policy," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 2893–2901, 2018.

[3] DLH Provinsi Jawa Timur, *IKPLH (Informasi Kinerja Pengelolaan Lingkungan Hidup) daerah provinsi Jawa Timur*, 2016.

[4] S. M. Bina, S. Jalilinasrabady, H. Fujii, and N. A. Pambudi, "Classification of geothermal resources in Indonesia by applying exergy concept," *Renewable and Sustainable Energy Reviews*, vol. 93, pp. 499–506, 2018.

[5] S. Maryanto, S. H. Siombone, A. Prayogo, T. Yulia, and R. P. H. Sari, "Preliminary study: density layer values estimation of volcano hosted geothermal area at Tiris Village, Probolinggo Regency, East Java, Indonesia," *International Journal of Applied Engineering Research*, vol. 13, no. 6, pp. 4385–4390, 2018.

[6] N. Ilham and S. W. Niasari, "Identification the geothermal system using 1-D audio-magnetotelluric inversion in Lamongan volcano field, East Java, Indonesia," *Journal of Physics: Conference Series*, vol. 1011, no. 1, p. 12029, 2018.

[7] S. C. Cox, C. D. Menzies, R. Sutherland, P. H. Denys, C. Chamberlain, and D. A. H. Teagle, "Changes in hot spring temperature and hydrogeology of the Alpine Fault hanging wall, New Zealand, induced by distal South Island earthquakes," *Geofluids*, vol. 15, no. 1-2, pp. 216–239, 2015.

[8] F. Deon, H. J. Förster, B. Wiegand et al., *Greenfield exploration of hidden magmatically driven geothermal systems in active subduction zones: case study Lamongan (East Java, Indonesia)*, World Geothermal Congress, 2015.

[9] M. R. Aqli, *Identifikasi struktur bawah permukaan daerah prospek panas bumi dengan metode gravitasi: Studi kasus di Daerah Mata Air Panas Padusan Desa Padusan Kecamatan Pacet Kabupaten Mojokerto*, Universitas Islam Negeri Maulana Malik Ibrahim, 2019.

[10] W. M. Telford, W. M. Telford, L. P. Geldart, and R. E. Sheriff, *Applied Geophysics*, Cambridge University Press, 1990, [Online]. Available: https://books.google.co.id/books?id=oRP5fZYjhXMC.

[11] W. B. Cumming, "Resource conceptual models of volcano-hosted geothermal reservoirs for exploration well targeting and resource capacity assessment: Construction, pitfalls and challenges," *Transactions - Geothermal Resources Council*, vol. 40, pp. 623–637, 2016.

[12] J. D. Kana, N. Djongyang, D. Raïdandi, P. N. Nouck, and A. Dadjé, "A review of geophysical methods for geothermal exploration," *Renewable and Sustainable Energy Reviews*, vol. 44, pp. 87–95, 2015.

[13] P. M. Sukendar, B. Sasmito, and A. P. Wjaya, "Analisis Sebaran Kawasan Potensial Panas Bumi Gunung Salak dengan Suhu Permukaan, Indeks Vegetasi dan Geomorfologi," *J. Geod. Undip*, vol. 4, no. 3, pp. 86–94, 2016.

[14] W. Utama, A. S. Bahri, and D. D. Warnana, "Analisis Citra Landsat ETM+ untuk Kajian Awal Penentuan Daerah Potensi Panas Bumi di Gunung Lamongan, Tiris, Probolinggo," *J. Fis. dan Apl.*, vol. 8, no. 1, article 120103, 2015.

[15] D. Handoko, A. L. Nugraha, and Y. Prasetyo, "Kajian pemetaan kerentanan kota semarang terhadap multi bencana berbasis pengindraan jauh dan sistem informasi geografis," *J. Geod. Undip*, vol. 6, no. 3, pp. 1–10, 2017.

[16] M. R. Khomarudin and P. Sofan, *Pemanfaatan Penginderaan Jauh untuk Mitigasi Bencana di Indonesia*, 2014.

[17] L. Handayani and D. D. Wardhana, "EKSPLORASI GAYABERAT UNTUK AIRTANAH DAN TOPOGRAFI BATUAN DASAR DI DAERAH Serang, Banten," *Ris. Geol. dan Pertamb.*, vol. 27, no. 2, pp. 157–167, 2017.

[18] J. Purnomo, S. Koesuma, and M. Yunianto, "Pemisahan anomali regional-residual pada metode gravitasi menggunakan metode moving average, polynomial dan inversion," *Indonesian J Appl Phys*, vol. 3, no. 1, pp. 10–18, 2016.

[19] U. Harmoko, M. H. Anggit, T. Yulianto et al., *Magnetic modeling of the Diwak-Derekan geothermal area with extension to Bawen, Central Java*, 2015.