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Geothermal exploration using lineament density analysis at Rajabasa Volcano, South Lampung

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Abstract

The research is located around Rajabasa Volcano, South Lampung Regency, Lampung Province, Indonesia. The research areas have unique geological conditions and arrangements. It is part of the caldera body estimated to have centralized geothermal potential. Identification of potential geothermal areas can be made using remote sensings such as lineament density analysis, slope, and land surface temperature with areas of approximately 190 square kilometers. Manually extraction of lineament density is dominated by the NW-SE direction with an anomaly of only 20 percent. While the lineament density process is automatically controlled in the NE-SW order, it is estimated that the anomaly density is around 80 percent which is suitable for the central, medial, and distal. The shape of the topographic relief has a reasonably high slope starting from 0 to over 55 degrees. The soil surface temperature ranges from 14 to 34 degrees celsius. The results of the data analysis variables in the research area should be suspected that the geothermal distribution potential of Rajabasa Volcano is estimated to be in the T0 N-NW zone, T1 E zone, and T2 S-SW zone.

Keywords: exploration geothermal; remote sensing lineament; South Lampung

1. Introduction

Lineament density analysis can serve as initial analysis in geothermal exploration using remote sensing data based on *Geographic Information System* (GIS). Lineament presents the capacity to characterize fault or fracture. It is one of the essential elements in the geothermal system evolution, in which this fault serves as the path for geothermal fluids with high permeability (Saepuloh et al., 2018). Additionally, lineament distribution shows the intensity variations of the faults, which further illustrates the reservoir condition to assess the geothermal system (Soengkono, 1999). Therefore, this study was carried out in the area of Rajabasa Volcano, South Lampung Regency, Lampung, Indonesia. This study site is 70 kilometers southeast of the provincial capital and takes 1 hour and 30 minutes to reach, as illustrated in Figure 1.

This research location presents uncommon traits. The Rajabasa Volcano consists of volcanic rocks, Rajabasa lava (RI), Rajabasa pyroclastic flow (Ra), Lava 845 (8451), Lava Balirang (BI), Balirang pyroclastic flow (Ba), ancient Pematang Taman volcanic products (PTv), and ancient Tangkil volcanic products (Tv) (Sarkowi & Wibowo, 2021), as presented in Figure 2. Additionally, the Kalianda geologic map exhibits geologic structure patterns and lineament structure heading in thenorthwest–southeast direction (Figure 2). Peta geologi lembar Kalianda menunjukan pola struktur geologi dan kelurusan struktur yang memiliki arah barat laut-tenggara (Mangga, 2010). Besides, a different lineament of contour leading to northeast-southwest and north-west-southeast have been reported, which is affected by the regional structure, such as the Semangko Fault (Daruwati, 2014). The local structure control triggers the manifestation of distribution in the area of Rajabawa Volcano. However, some geothermal systems have no ability to bring up manifestation due to the absence of geological structure control or other factors.

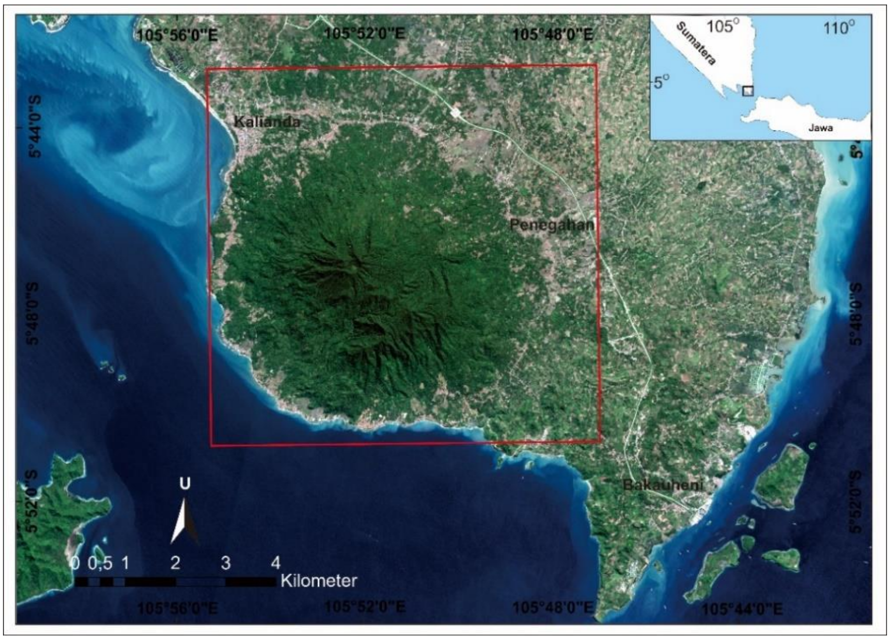

Figure 1. Map of Research Location in Rajabasa Volcano, Lampung, Indonesia
Source: U.S. Geological Survey (2021)

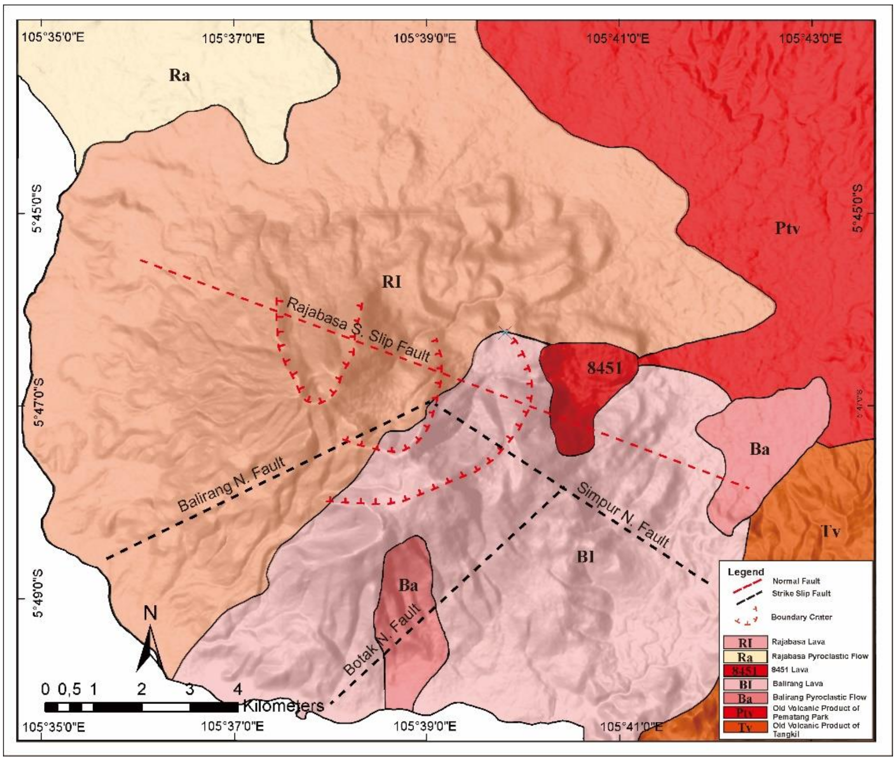

Figure 2. Geologic Map of Rajabasa Volcano in South Lampung, Indonesia
Source: Sarkowi and Wibowo (2021)

The Rajabasa Volcano evolution contains: 1) the construction phase of the Rajabasa Volcano composite, 2) the destructive phase of pre-Rajabasa and caldera construction, 3) the initial phase of the pre-Rajabasa volcano, 4) the Rajabasa Volcano phase with progressing monogenic eruption within the Rajabasa Volcano pre-caldera (Sutikno Bronto, Asmoro, Hartono, & Sulistiyono, 2012). During the pra-caldera phase, the residual heat activity of magma provides the most excellent situation for geothermal exploration. Glassley (2014) described that the apparent target of geothermal exploration is the active volcano or volcano, which has been active for thousands of years (dormant). Stratigraphic grouping systematically determines the age of a geothermal system, starting from the arc, super brigade, brigade, crown, and hummock.

Hummock offers geothermal systems with a limited lifespan, while the brigade and super brigade are supposed to present the geothermal system with a longer lifespan (Bronto, Sianipar, & Pratopo, 2016). Further, Wohletz and Heiken (1992) explained that the caldera thermal model mainly demonstrates conductive high heat flow and most convective heat transfer on the fault zone. The amount of hydrothermal system highly relies on the permeable zone area under the caldera. Accordingly, each volcano has distinct singular characteristics.

This study uses a remote sensing method. This method has been extensively investigated. It is a feature based on system information operating on an object with no direct connection to the platform (Gupta, 2017). Remote sensing adoption in the study of geothermal is crucial, especially in the initial stage, such as in the lineament density analysis (LDA). A previous study reports that a simple analysis of digital surface data can be utilized as an additional tool for exploring and assessing geothermal systems (Soengkono, 2000). A processing method has been carried out by Bromley, Ashraf, Seward, and Reeves (2015) by conducting an investigation that enables the use of remote sensing techniques to supervise the surface geothermal feature in a more extensive area. Therefore, this study used comparative variables, consisting of lineament density analysis (LDA), slope, and land surface temperature (LST) anomaly, to investigate the initial mechanism of manifestation distribution using the remote sensing method.

2. Method

This study was completed using a remote sensing method identified based on the secondary data, similar to prior studies in geology, vulcanology, geology structure, and geothermal. The primary data of lineament density analysis (LDA), slope, and topography were garnered through shuttle radar topography mission (SRTM) and AsterDEM https://earthexplorer.usgs.gov/. Meanwhile, the vegetation density correction of normalized difference vegetation index (NVDI) was completed using Landsat 8, while the *land surface temperature* was observed using thermal surface anomaly (MODIS) land surface temp and emiss-v6 https://earthexplorer.usgs.gov/. For the visualization, we conducted lineament identification manually and automatically. Aside from the lineament, we also analyzed the counter density, slope shader map, and land surface temperature as the advocating data, as shown in Figure 3.

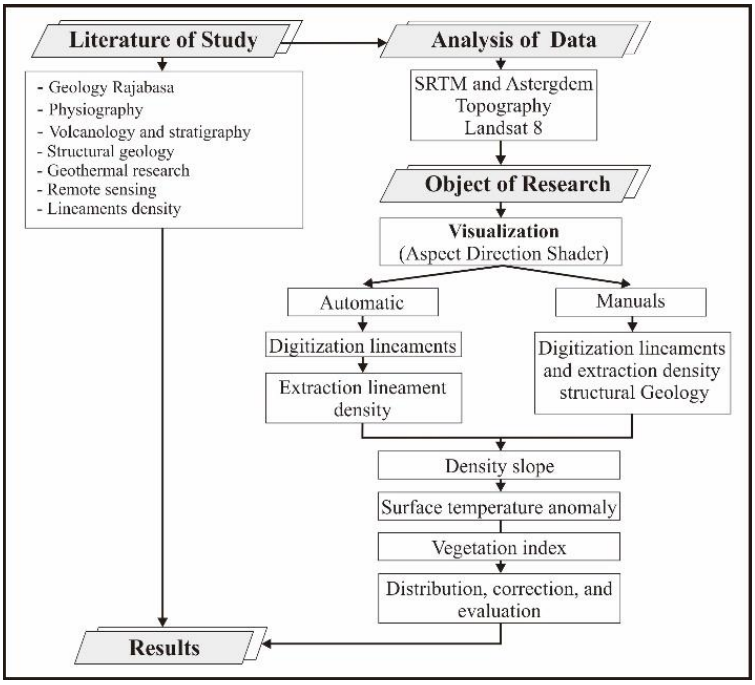

Figure 3. Flowchart of Research Method

The analysis was conducted using shuttle radar topography mission (SRTM), topography, *Landsat* 8, and digital elevation model (DEM) with the fundamental data in 90-30 meter resolution. The majority of data being used in the analysis contained line components for the estimation of the dimension of length, orientation, number, and density on its data processing (Thannoun, 2013). In this study, our analysis process included reflection of surface hue, focusing on the direction shader aspect from morphology extraction, non-subjective lineament digitation based on the geology concept with N-E E-S S-W W-N trend of lineament pattern, and spatial analysis on density trend line extraction. Additionally, we also carried out a manual analysis to attain more significant variables. This analysis was carried out by hue reflection on aspect direction shader digitation lineament with N-E E-S S-W W-N direction, followed by lineament digitation export, grid map in 1x1 (km) then export, exported data overlay on the new worksheet with lineaments from the grid in the form of a number, then we extracted the digital gridding report data in the form of anomaly. Land surface temperature (LST) was used to measure the surface temperature of the heat anomaly. The apparent indication of highly accurate data is different land surface temperatures showing closer recording periods and accuracy of land cover (Salih, Jasim, Hassoon, & Abdalkadhum, 2018). However, excellent condition is not always exhibited in every climate. Karnieli et al. (2010) reported that the general perception of land surface temperature commonly presents minimum or negative correlation observed from a variety of locations, seasons, and types of vegetation. Consequently, we also utilized LST as a part of our research variable by using MODIS Land Surface Temp and Emiss V6–MODIS-MOD11A2 V6, as well as spatial analysis with special input in calvin (*0.02) and celcius (–273.15). In the end, this study was expected to describe the different types of geological control structure in which the manifestation frequently emerge in the estimated zone. Therefore, distribution manifestation observed using the remote sensing method produced high assurance on surface geothermal manifestation sources in the Rajabasa Mountain area in the initial phase.

3. Results and Discussion

The results of the analysis conducted through the remote sensing method on the Rajabasa Volcano produce a pattern of lineament density on its geological structure, slope distribution, and land surface temperature, which serve as the explanatory factor of the geothermal exploration target. A previous study employing the same analysis also reported the main trend of NW-SE trend (Darmawan, Setijadji, & Wintolo, 2013). Meanwhile, a similar study carried out in different locations revealed that the primary trend pattern in the fault system includes the Sumatera, Java, and Meratus pattern, which implicates the lineament distribution and controls on the fault's permeability where the geothermal manifestation is developing (Saepuloh et al., 2018). The permeability index can be examined and generate a correlation coefficient toward the geological structure with lineament density (Heriawan, Syafi'i, Saepuloh, Kubo, & Koike, 2021). Thus, the density of each lineament pattern established in the geothermal system area presents a more significant contribution to geothermal exploration.

3.1. Lineament Density Analysis

The analysis variables of lineament density toward the geological structural condition in the Rajabasa Volcano area were divided into two analysis subjects, namely the automatic and manual lineament, with extraction directions of north-east (q1), east-south (q2), south-west (q3), dan west-north (q4), as illustrated in Figure 4. The automatic q1 q2 q3 and q4 lineament generated 345 extracted unit lines, while the manual q1 q2 q3 q4 lineament contained 41 unit lines. These two analyses were carried out using a 1x1 (km^2) grid concept with different directions of dimension following the area's morphology. The data garnered through automatic lineament density was highly dominated by NE-SW direction. Besides, the lineament frequency on the ± 190 km^2 area was only observed in 20% of the area. From this finding, we presumed that the structure control only emerges in the area with a high anomaly, while the area with stable lineament was not digitized, indicating no influence of the structure. Meanwhile, from the manual lineament density process, we observed anomalies, as illustrated by the contrasting hue. The lineament anomaly was dominated by NW-SE direction. Besides, the density of extraction from an area ± 190 km^2 is estimated to represent 80% structure control within the area. Thus, our two analyses produce different results, with the results of manual lineament analysis presenting higher frequency than the automatic lineament primarily in the central, medial, and distal parts, as illustrated in Figure 5. This finding may be caused by different lineament digitation quantity, digitation length, and subjectivity levels. The tighter and dense lineament will result in better extraction and data analysis.

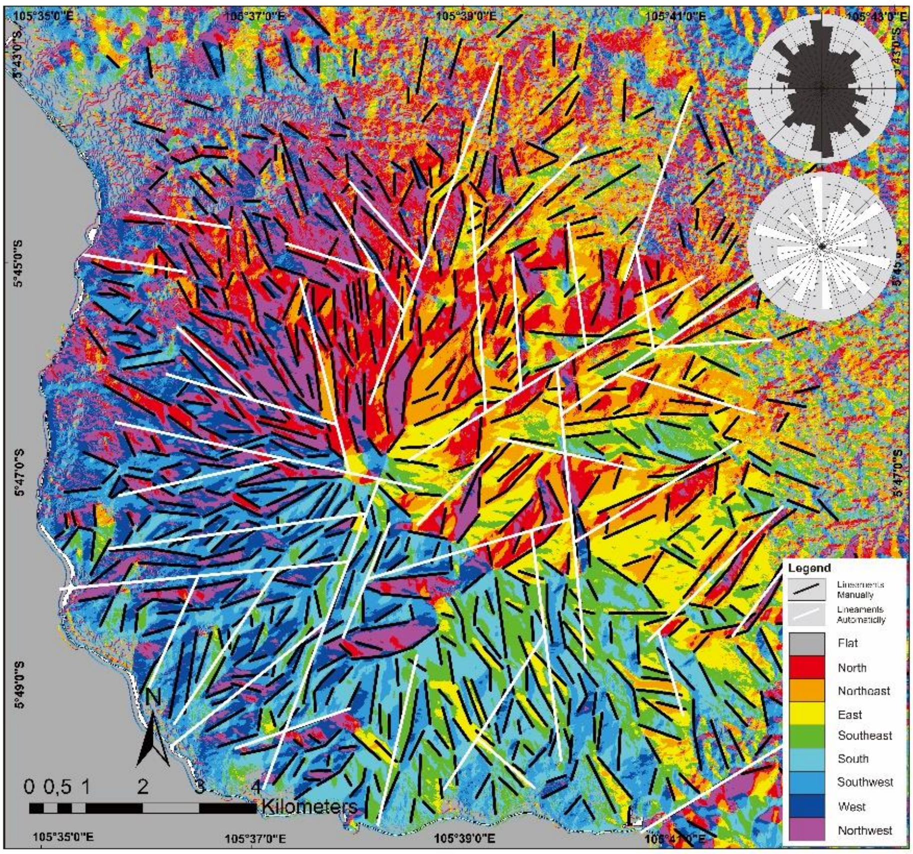

Figure 4. Lineament Digitation Map on Rajabasa Volcano Area in Visual Aspect Direction Shader Lineament through Manual (Black) and Automatic Lineament (White)

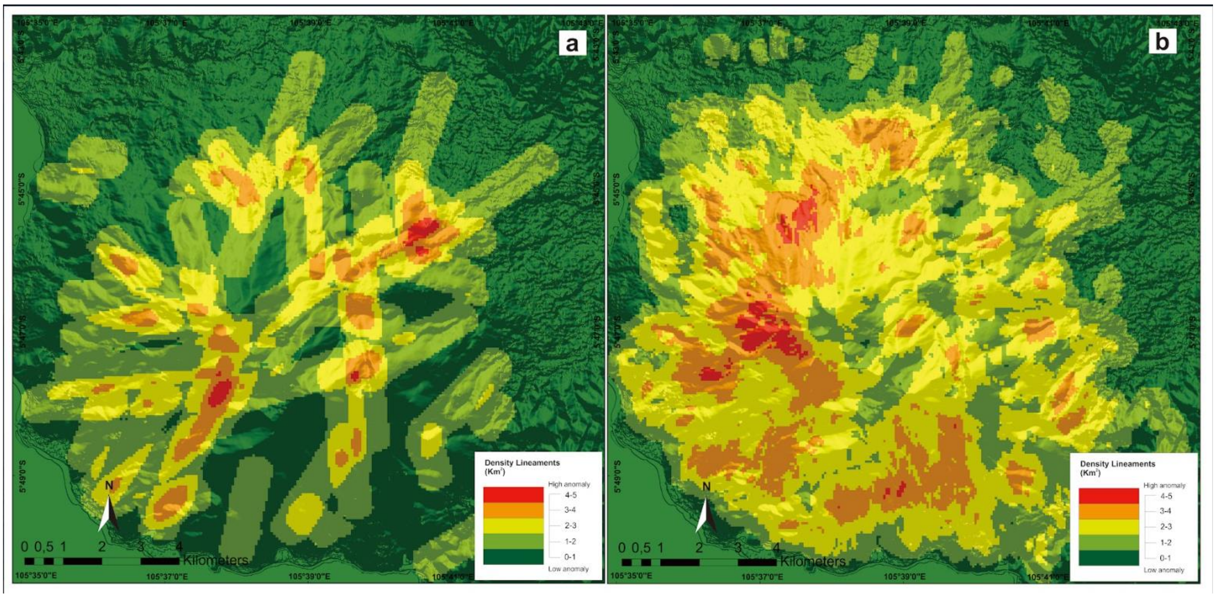

Figure 5. Lineament Density Extraction in the Rajabasa Volcano Area a) Automatic Lineament Extraction centralized in NE-SW Direction, b) Manual Lineament Extraction Centralized in NW-SE Direction

3.2. Distribution of Slope

Fundamentally, the slope is associated with rocks and structure, but in geothermal exploration, it is closely related to the location or zone of surface manifestation. Our data suggested that the slope in our research location varies greatly, from 0° to >52°, as shown in Figure 6.

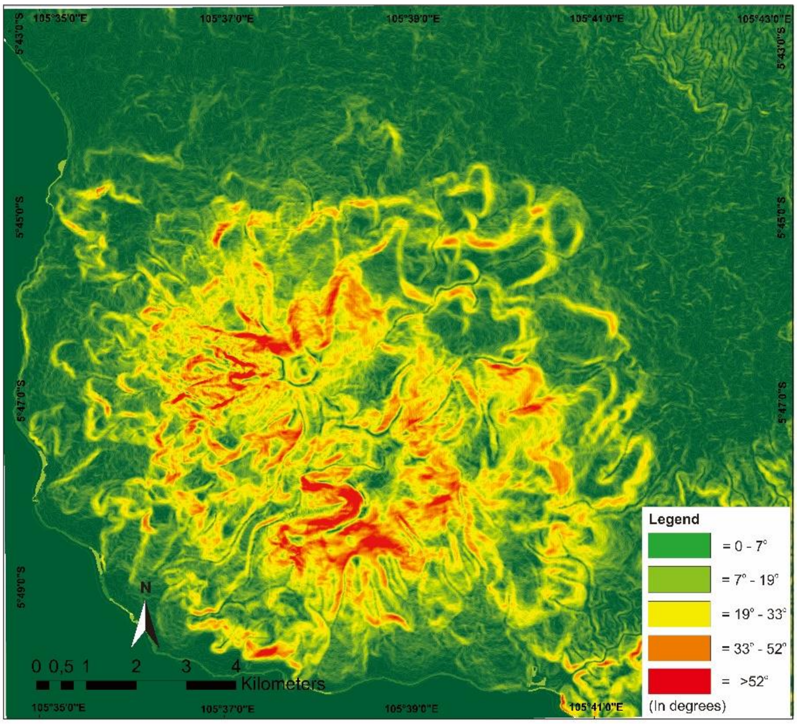

Figure 6. Map of Slope in the Rajabasa Volcano Area

3.3. Land Surface Temperature

The measurement using land surface temperature (LST) was carried out to identify the temperature dissemination indicating the geothermal activity. The display from MODIS land surface and Emiss-V6 was attained from the recording carried out in August 2022. During the recording, the surrounding situation was free from clouds, enabling us to gather images with relatively great quality. For the results of LST measurement, we attained different ratios, ranging from >14°- <34° (in celsius), as shown in Figure 7. However, the obtained vegetation may present inaccurate information due to the not properly recorded geothermal manifestation caused by comparably thick vegetation cover. If this situation occurs, then vegetation correction is required. Vegetation index correction between the red wavelength toward the near-infrared can be carried out by applying the Normalized Difference Vegetation Index (NDVI) (NDVI = (Band 5 – Band 4)/(Band 5 + Band 4)) (Avdan & Jovanovska, 2016). The vegetation density illustrates a comparably low amount of non-vegetation area along with dominating high vegetation, as presented in Figure 8. In relation to the vegetation density, some observed temperature anomaly spots indicated geothermal activity in the form of surface manifestation in the medial part, specifically on the north and southeast sides of Rajabasa Volcano.

The LST measurement relies heavily on the wave or situation during the data recording. The temperatures produced from the infrared brightness between locations were different, which may be caused by the land cover. As LST is an active analysis, it also contains recording transmission processes. Therefore, the results tend to be less accurate, requiring repeated measurement in different time units to attain a more apparent temperature in a specific area. Better data recording results in higher accuracy.

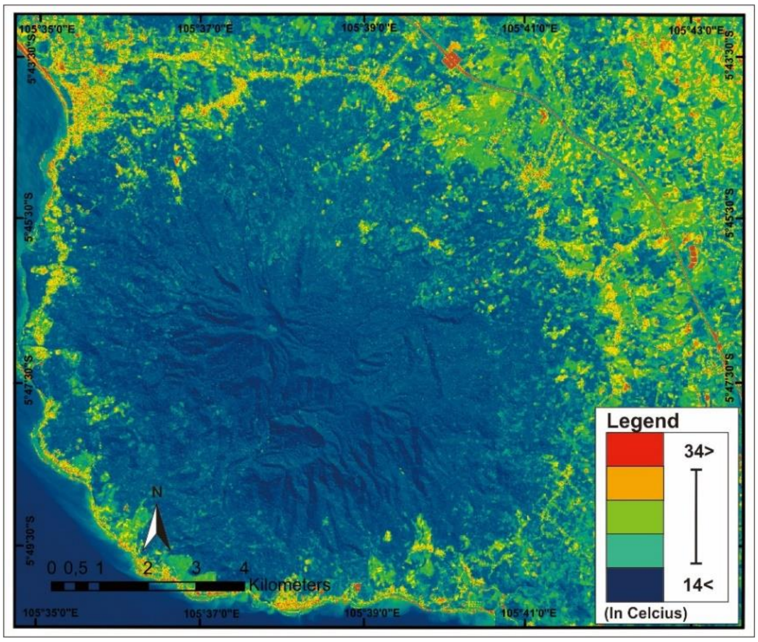

Figure 7. Map of Land Surface Temperature (LST) of Rajabsa Volcano Visualized in Celcius (°C) with Low (Blue) and High (Red) Temperatures

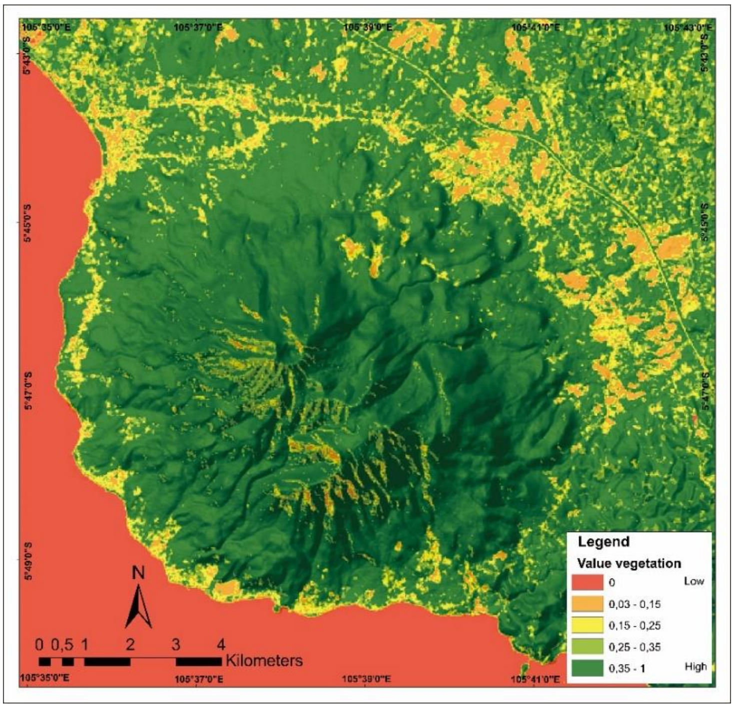

Figure 8. Map of Vegetation Spread in Rajabasa Volcano Area

The results of LDA, slope and LST analysis in the Rajabasa Volcano area indicated a zone of geothermal activity, as shown in Figure 9. We conducted lineament density analysis (LDA) in the Rajabasa Volcano area using remote sensing, supported by parameter data slope and data obtained from Land Surface Temperature (LST). The results of LDA suggested the NE-SW and NW-SE trend of the lineament pattern, indicating the role of the geological structure process, which associates with the geothermal manifestation distribution around the Rajabasa Volcano. The obtained lineament and contour density clearly illustrates the geological structure and activities in the Rajabasa Volcano system. The results showed the presence of relatively high LDA anomaly in q1, q2, q3, and q4. Further, the mapping of the high LDA zone represents the existence of a fault as a trigger of geothermal manifestation on the permeable rocks. This structure vertically cuts the rocks under the surface, in which the heat flow interacts and spreads around the weak zone.

In addition, the slope in the Rajabasa Volcano area is quite varied, in which the central-medial area ranging between 33° - >55° contains high LDA. However, the LST analysis showed the extraction visual only in some points, showing the geothermal activities in the body part of the volcano caused by the spatial resolution and vegetation cover. The results of standard deviation calculation involving a number of variables generated highly significant results with relatively heterogeneous data. The high standard deviation suggests a wider data range toward the sample population, as in Table 1. The linear regression correlation between the lineament variables toward the land surface temperature was R^2 0.2322, while the correlation between the slope and lineament was R^2 0.0099, categorized as moderate and low, respectively, as shown in Figure 10. Thus, these correlations were accepted.

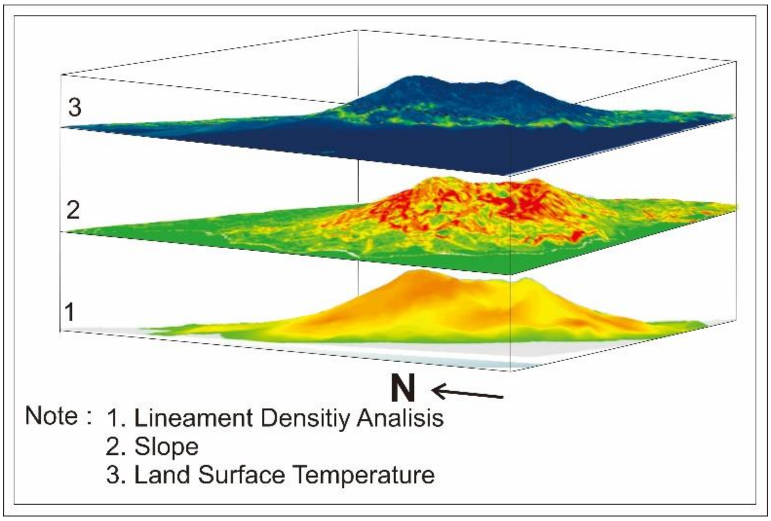

Figure 9. 3D Integration of Data Analysis: (1) Lineament Density Analysis, (2) slope, (3) Land Surface Temperature

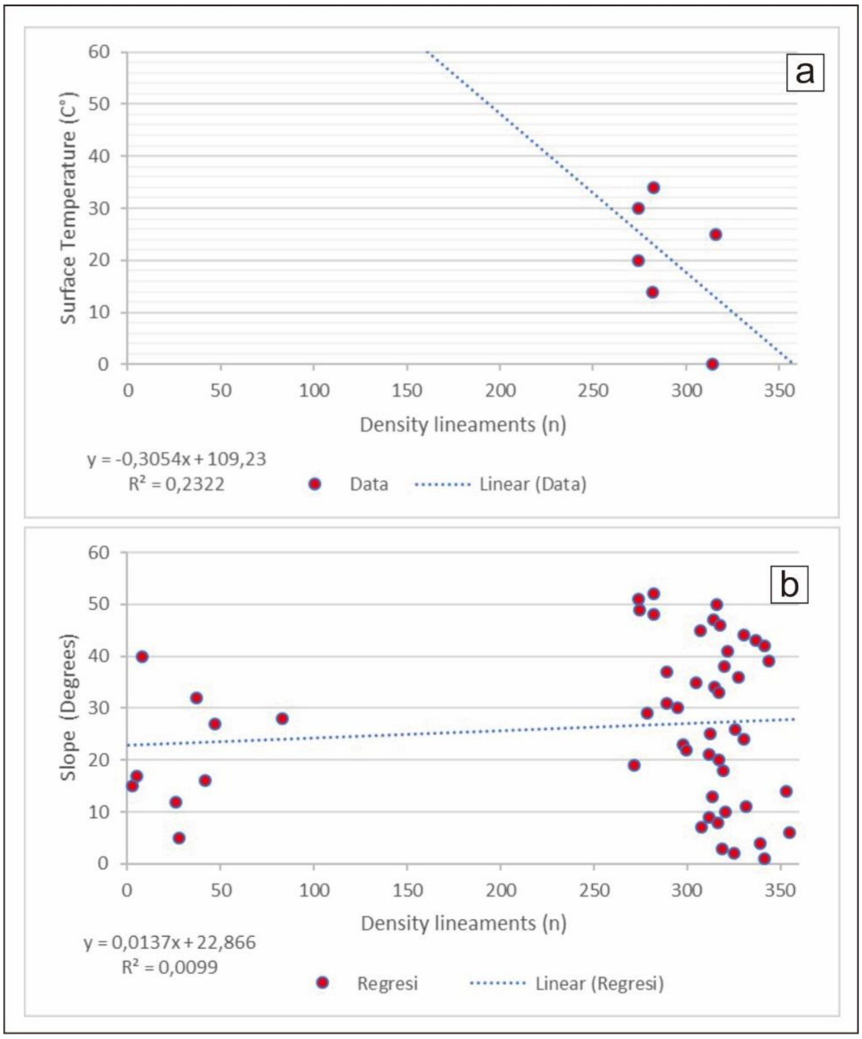

Figure 10. Linear Regression Correlation between Variables: a) Lineament toward Land Surface Temperature, b) Slope toward Lineament

Table 1. Standard Deviation Variables on Sample Data

Variable	N	Sum	Mean	Std. Deviation
Lineament	345	66964	194.10	143.560
LST	34	124	20.67	11.961
Slope	52	1378	26.50	15.155

Therefore, our research location presents a geothermal prospect associated with the volcanic system. Integration of data analysis results suggested that our research location can be divided into three potential zones of surface geothermal manifestation, namely: 1) T0 zone in the north-northwest part of Rajabasa Volcano developed in the Rajabasa lava unit with strike slip fault structure concentration, 2) T1 zone in the west part of Rajabasa Volcano developed in the Rajabasa lava unit with Balirang normal fault structure serving as the output lane of geothermal manifestation, 3) T2 zone in the south-southwest part of Rajabasa Volcano developing in the Balirang lava geological structure in the Banding and Simpur normal fault, in which the manifestation is estimated to develop surrounding the fault area, as shown in Figure

11. The targeted zone is estimated to develop in the up flow and outflow parts. The heat transfer process from within to the surface originates from the rocks that still store heat or attain heat directly from the magma, so the fluid circulates through the fracture and gets into the surface in the form of manifestation.

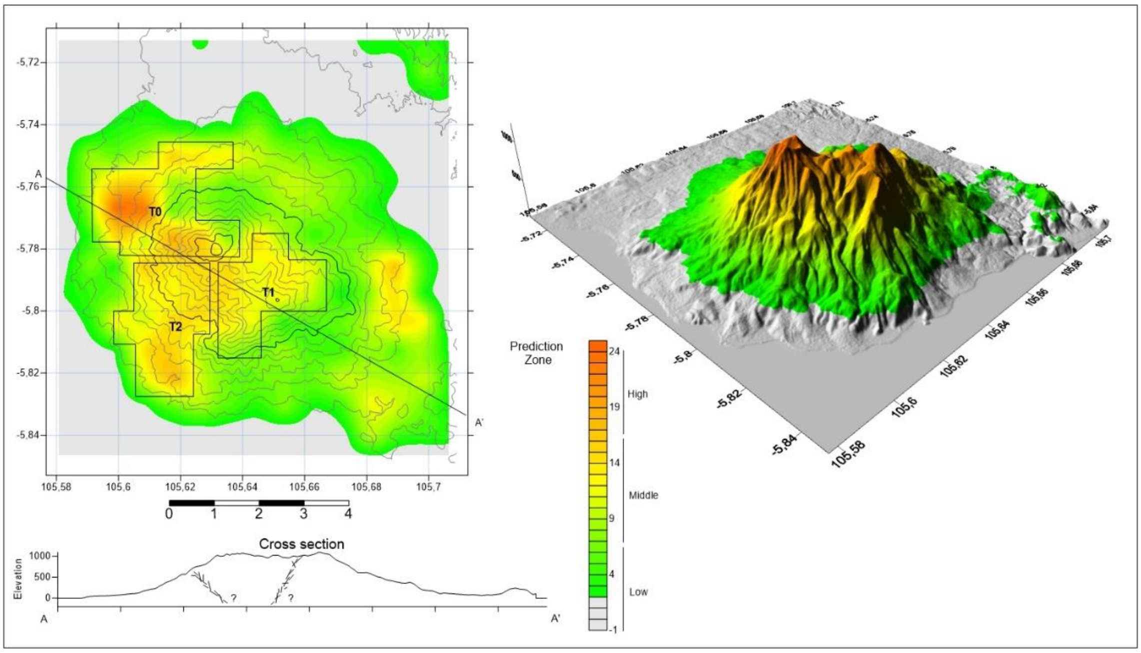

Figure 11. Maps of Geothermal Potential Conjectures of T0, T1, and T2 Based on Data Analysis Data Variable

4. Conclusion

Our research location has an area of ± 190 km^2. The Rajabasa Volcano presents a relatively steep to moderate slope. Our lineament density analysis showed NE-SW and NW-SE lineament trend patterns, estimated to contain manifestation. Meanwhile, LST analysis showed a sufficiently excellent distribution of heat points, but the estimation of the manifestation area was challenging. Besides, the vegetation of our research area also requires further consideration. The Rajabasa Volcano presents geothermal potentials with a volcanic system divided into the T0, T1, and T2 zones. However, further analysis is still needed to generate more extensive research using a different method to attain more diverse data variation.

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