



Spatial Analysis to Determine the Geothermal Potential Index: The Case Study of Dieng Geothermal Complex

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Abstract: The exploration is the activity of search areas that have the potential natural resources. Such as the exploration of geothermal potential. It can be using of spatial analysis. Spatial analysis can be base modeling of the geothermal potential in the research area. The analytic hierarchy process (AHP) is a fundamental analysis of the modeling data, where the comparison matrix from the analysis like surface temperature, lineament, and eruption center. The result of modeling in the Dieng volcanic complex has identified as the geothermal potential area. The potential area is around of G. Pakuwaja, G. Pangonan-Merdada, and G. Pagerkandang. So that the integration method of the modeling can be used as the method of the geothermal exploration activities.

Keywords: Spatial Information, analytical hierarchy process (AHP), Geothermal Potential Index

1. INTRODUCTION

The exploration of geothermal has a long process. Such as the cost is incurred during initial exploration and the uncertainty of geothermal exploration very high (Ngugi, 2014). The geothermal exploration expertise involved is geologists (geological structure, volcanology, and manifestations), geochemists (isotope analysis of fluids and rocks), and geophysicists (electromagnetic and seismic analysis) (Bruhn et al., 2011). The exploration activities can be use simplify an area in relation to geothermal potential. Such as geographic information systems (GIS) to application in the geothermal exploration activity. The geographic information system (GIS) is a analysis without touching the research object like keep data, integration data, and modeling data conform to the object of analysis Gupta (2017). One part of the GIS is information spatial analysis. The spatial analysis is fundamental to modeling. Such as in geothermal exploration activities, where the data such as geological, geochemical, and geophysical are determine the location of the potential geothermal (Noorollahi et al., 2008).

Therefore based on the discussion above, the researcher will apply to research geothermal exploration based on spatial analysis. The method integration from this analysis is the analytical hierarchy process (AHP).

The purpose of this research is to build spatial information system data based on the variable data researchers use. So that, it produces a model of geothermal exploration in the research location. Moreover, the analysis to find the geothermal potential index of the area from the analytical hierarchy process (AHP) method.

The research location is in the Dieng geothermal complex (Figure 1). It was chosen to test the validity of this research method for geothermal exploration activities. The problem of the research is how to build spatial data for the exploration of geothermal. Then how to integrate the data with the method analytic hierarchy process (AHP) test. The problem boundaries in this research is lineament density, surface temperature, and eruption centers.

The benefits of this analysis can be providing information of the geothermal potential index (GPI). Moreover, the variable surface temperature, eruption centers, and lineament density, it will be fundamental for data integration to explain the model geothermal potential index in the research area. The geothermal potential index zone (GPI) can be used as a reference for exploration activities to research the geothermal potential. Moreover, GPI can be used as additional data in determining areas of geothermal potential, whether own of geothermal potential or not.

2. MATERIALS AND METHODS

2.1. Geology of the Research Area

The stratigraphy of the research area is a volcanic complex, which is composed of a series of volcanic rocks and young volcanic deposits Quaternary, such as Old Dieng Deposits, Second Dieng Deposits, Young Dieng Deposits, and Alluvium Deposits (Sukhyar et al., 1986). Moreover, according to Boedihardi et al., (1991), the lithology of the Dieng volcanic complex was constructed by the lava, tuff breccia, lava domes, and altered rocks. Meanwhile, based on the period of volcanism the Dieng volcanic complex was built during three periods of volcanism (Harijoko et al., 2016):

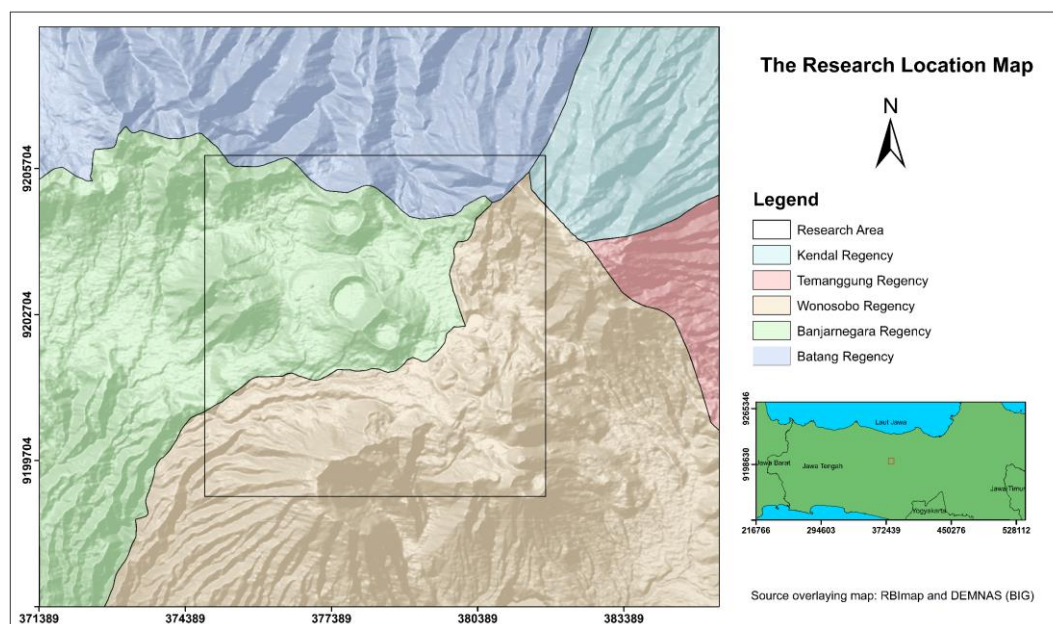


Figure 1. Location of the research area.

- Pre-collapse volcanism episode (G. Prah, G. Nagasari, G. Sidede, and G. Bisma);
- The second volcanism episode (G. Pagerkandang, G. Bucu, and G. Pongan-Merdada);
- The youngest episode of volcanism (G. Kendil, G. Pakuwaja, G. Sikunir, G. Prambanan, and G. Seroja). G is the name spelling of the Gunung in Indonesia or mountain.

Moreover, the geological structures were developing in the research area like the strike-slip fault in the west of G. Prambanan, the strike-slip fault in the northeast of G. Pagerkandang, the strike-slip fault in the west of G. Kendil, and normal fault in the southern part of G. Prau (Shalihin et al., 2022). The control of geological structures that occur can cause fractures. It is related to increasing permeability values in the area. Moreover, the control of geological structures can bring out the flow of geothermal fluid and form the surface manifestation or altered ground. If observed from the volcanic structure, the Dieng volcanic complex has evolved into a caldera with an estimated caldera diameter of 6-7 km. Where the boundaries around this caldera system are G. Bisma, G. Nagasari, and G. Prah (Sirait et al., 2015).

2.2. Data Source

The sources of data in this research is from institutions data, previous research, and field studies. Such as the source of data lineament is the DEMNAS image from <https://tanahair.indonesia.go.id> (BIG, 2018). The source data of surface temperature is field studies. The amount of data surface temperature is 128 measurement points of the several research locations. Meanwhile, the source data of the eruption center is previous research, such as periods and age of volcanism.

Table 1. Element index of the AHP method (Saaty, 1990)

Mark	1	3	5	7	9	2,4,6,8
Index	S	Slp	Lp	Sp	Mp	M
S: Same Slp: A little more important LP: More important Sp: Very important Mp: Absolutely important M: Medium						

Table 2. Random consistency value (RI)

n	1	2	3	4	5
RI	0.00	0.00	0.58	0.90	1.12
n	6	7	8	9	10
RI	1.24	1.32	1.41	1.45	1.49

2.3. Analysis Method

The analysis method of the research uses the analytical hierarchy process (AHP). AHP developed by Saaty (1990), AHP is a multi-criteria analysis of research variables into a pattern or main idea of the research. Moreover, the analysis of AHP is a analysis very complex, where the relationship between variables is assessed base on important variables (Moustafa, 2015). The results of using the AHP method to modeling of GPI have very good ratio levels. Such as the result of a study of the GPI in the Agri Province of Eastern Turkey by the AHP method has the geothermal potential area of 20.8%. It is value geothermal potential of the Agri Province which can be explored further (Erhan & Şehnaz, 2021). From the explanation above, assessments of the AHP method are based on the level of importance of the relation between variable data like same, little more important, more important, very important, absolutely important, and medium (Table 1).

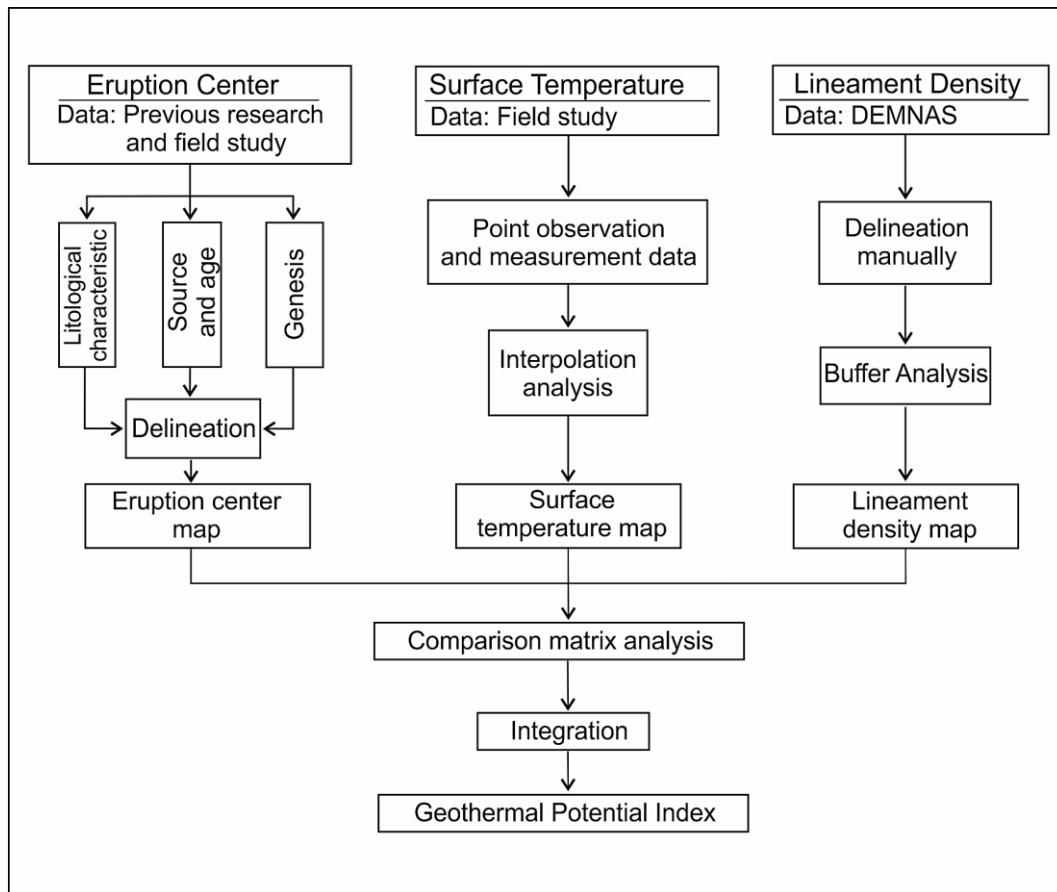


Figure 2. Research methods.

The variable in this research has used three variables. If the matrix accuracy value in this study is using 3 x 3 matrix, so that the comparison of the RI value of 0.58 (Table 2). The consistency index (CI) is obtained from equation (1). Where lambda is obtained from the times between parameters and weights. Additionally, to finish consistency ratio (CR) requires equation analysis (2) to produce ratio levels in data analysis. If the consistent ratio (CR) value less than 0.1 or equal to less than 10%, so the matrix is consistent.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

Where:

- n = Number of variables
- $\lambda_{\max}$ = Vector eigenvalue
- CI = Consistency index
- RI = Random consistency index

The analytical variables of the research are surface temperature, lineament density, and eruption center (Figure 2). Meanwhile, spatial information analysis used is band ratio, digitization, and interpolation. Then, for the modeling of the geothermal potential index, the data integration analysis could use operations weighted overlay. Weighted overlay has been used by previous

researchers, such as (Pazand et al., 2011) and (Moustafa, 2015), which the researchers then applied to this analysis.

a. Lineament Density

Analysis of lineament is a analysis of the reflection of geological structure. Lineament is a straight or curved line drawn on the map. The lineament density result is the mapping of control from the pattern geological structures that happen (Army & Saepuloh, 2020). Lineament can be achieved through two visual processes. Such as processing manually or automatically, it can be the analysis to compare which method most closely approximates the actual geological structural conditions of lineament analysis (El-Sawy et al., 2016).

The lineament analysis of the research using manual processing. The manual lineament could be identified based on the ideal topographic shape, such as the delineation lineament of the valley between two hills, the ridge of a hill, and the valley at the foot of a hill (Yamaguchi, 1985) (Figure 3). Lineament density analysis can integrate all data features of lineament, which indicates the presence of geological structures.

b. Surface Temperature

The Surface temperature analysis can be proven effective in the analysis of the surface geothermal activity (Wang et al., 2019). Surface temperature

analysis can be done with direct measurements and record temperature anomalies in the field. The next step analysis, uses the interpolation with the kriging concept (Figure 4). The kriging interpolation method is a interpolation method using certain known point values to predict unknown observation areas (Matehron, 1976). The kriging formula is commonly used like the following (3), where X_i represents the distance and λ_i represents of the weight or value of that point.

$$Z^* = \sum_i^n \lambda_i X_i \quad (3)$$

Where:

Z^* = Predicted value

X_i = Value distance of observation -i

λ_i = Value weight of the point -i

c. Eruption Center

The volcano is one of the high morphological forms, where magma or gas come out simultaneously to the earth's surface through a main vent, and then rocks accumulate around the eruption center to form the body of a volcano (Macdonald, 1972; Bronto et al., 2006). Identification of this volcano is also related to the eruption center. The parts of the structures volcano such as crown (Khuluk) has a short-live geothermal system meanwhile, brigade (Bergada) and super brigade (Manggala) should have a long-live geothermal system (Bronto et al., 2016).

Identification of eruption centers can be done by the analysis characteristics of lithology, age, and genesis of the volcano (Anonym, 1996). Identification of volcanic cones could use the DEMNAS data. Where the structure of the cones can still recognized using data DEM. The stratigraphic units can be grouped into several groups as follows (Table 3). The researcher takes

data on the formation of eruption centers from previous researchers like (Nurpratama et al., 2015) (characteristics of lithology), (Sukhyar et al., 1986) (source), (Harjoko et al., 2016) and (Boedihardi et al., 1991) (age and genesis of volcano). Moreover, field study data needs to increase understanding of the eruption center in the research area. After that, the researcher arranges the eruption center of the Dieng volcanic complex into the spatial data.

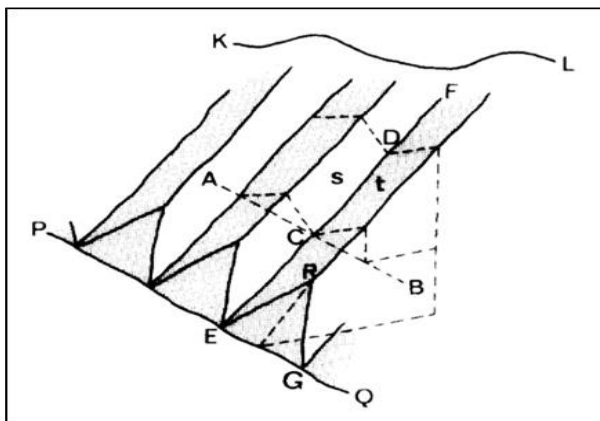


Figure 3. The measurements of lineament analysis (Yamaguchi, 1985).

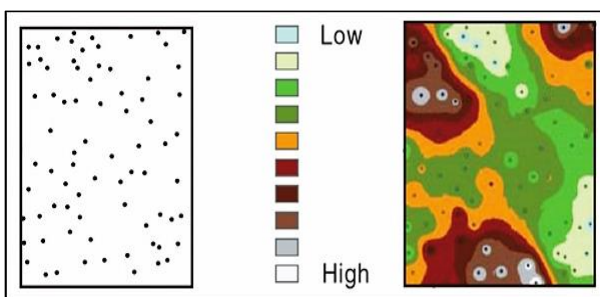


Figure 4. Map interpolation model with input point data (ESRI, 2001).

Table 3. Volcano stratigraphy (Anonym., 1996)

No	Unit	Information
1	Crown	The association of rocks or deposits generates one or more eruption points that build one volcanic body. It is mapped on the scale of 1:50.000.
2	Hammock	The part of the volcanic body is forming as a result of eruption centered on the body of the volcano, either as a central eruption or parasitic eruption. It is mapped on the scale of 1: 50.000.
3	Brigade	This unit includes the distribution of rocks and volcanic deposits resulting from two or more hammocks and correlated with the formation of volcanic calderas. It is mapped on the scale of 1:100,000 or larger.
4	Super brigade	The stratigraphic unit has more than one brigade, usually mapped on the scale of 1:100,000 or larger.
5	Arc	The unit contains a series of volcanic units built by the same tectonics. Usually mapped at a scale of 1:1,000,000 or larger.

3. RESULTS AND DISCUSSION

The study results explain how to obtain data, build spatial information, and modeling, where the result of modeling can explain the geothermal potential area. The modeling analysis in this research is integrated based on the AHP method, where the variable analysis includes like lineament density, surface temperature, and eruption center.

3.1. Lineament Density

Lineament density analysis features start with the use of DEMNAS data in the display aspect direction shader. Identification features lineament of the manual analysis has the total 501 digitized lines data (Figure 5a). Where the lines are a manifestation of the geological structure in the research area. From this analysis, the lineament density index has a high index with a brown color, and the lineament density index for low with a white color. The highest lineament density has dominated in the north-west side of G. Bisma, the west side of G. Kendil, the east side of G. Pagerkandang, the southeast side of G. Pangonan, and the southwest side of G. Pagerkandang (Figure 5b). The result of lineament density analysis in the research location has indicated control by the geology

structure. The controls of structure geology can find out and predict areas that have permeability from this analysis.

3.2. Surface Temperature

The surface temperature is analysis used to determine thermal anomalies in areas of geothermal activity. The data analysis of surface temperature anomalies was directed measurements in the field using the thermocouples tools (in °C). The grid is a technical method to determine sample points. The total number of measurements was 128 measurement points in several locations (Figure 6a). The research area has an anomaly surface temperature. Variations of surface temperature in the study areas have some variation, such as normal temperature and abnormal temperature (Figure 6b). The normal temperature has around 14-24 °C. Meanwhile, the abnormal range has > 34 °C. The anomalies abnormal of the surface temperature have correlated with the manifestation activity in the research area. Such as G. Pangonan and G. Pagerkandang areas have manifestations like mud pools, hot springs, fumarole, steaming ground, and warm ground.

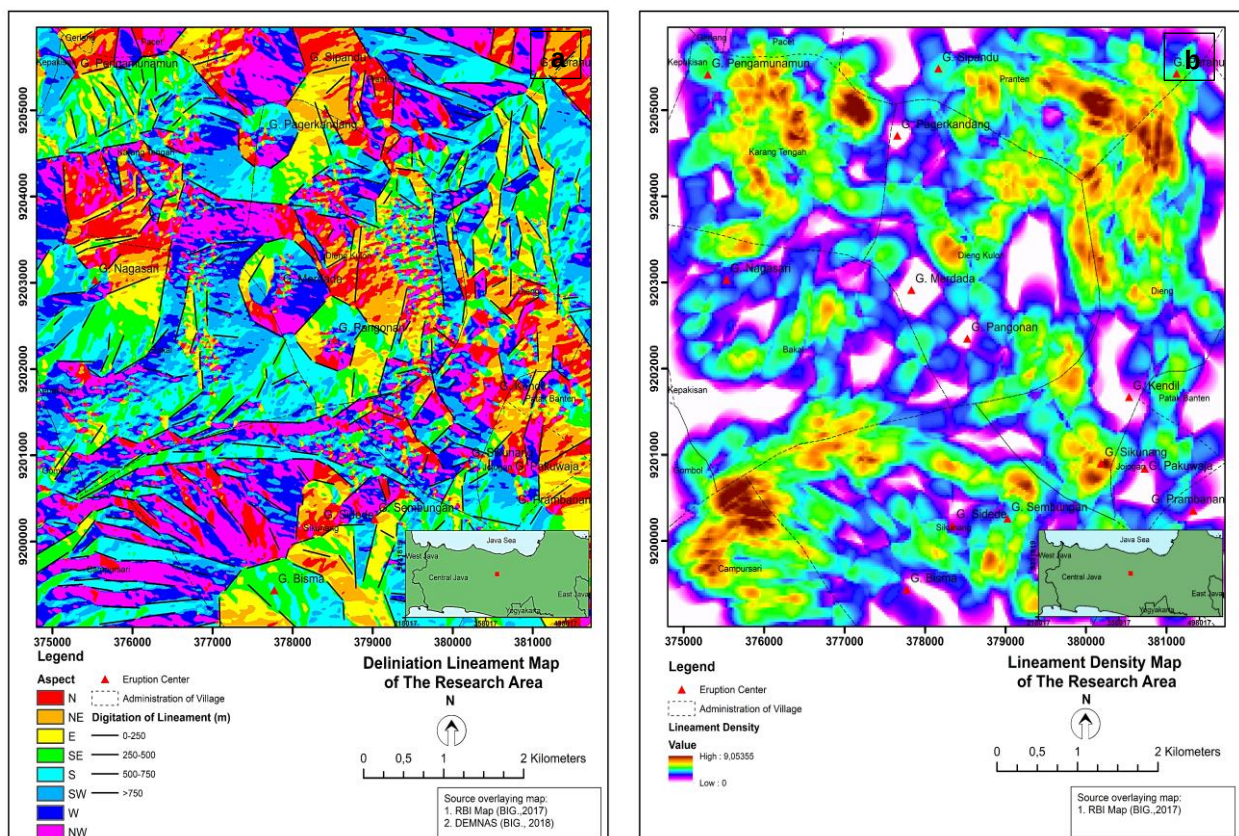


Figure 5. a) Results of delineation lines on the data aspect, b) Result of map lineament density analysis.

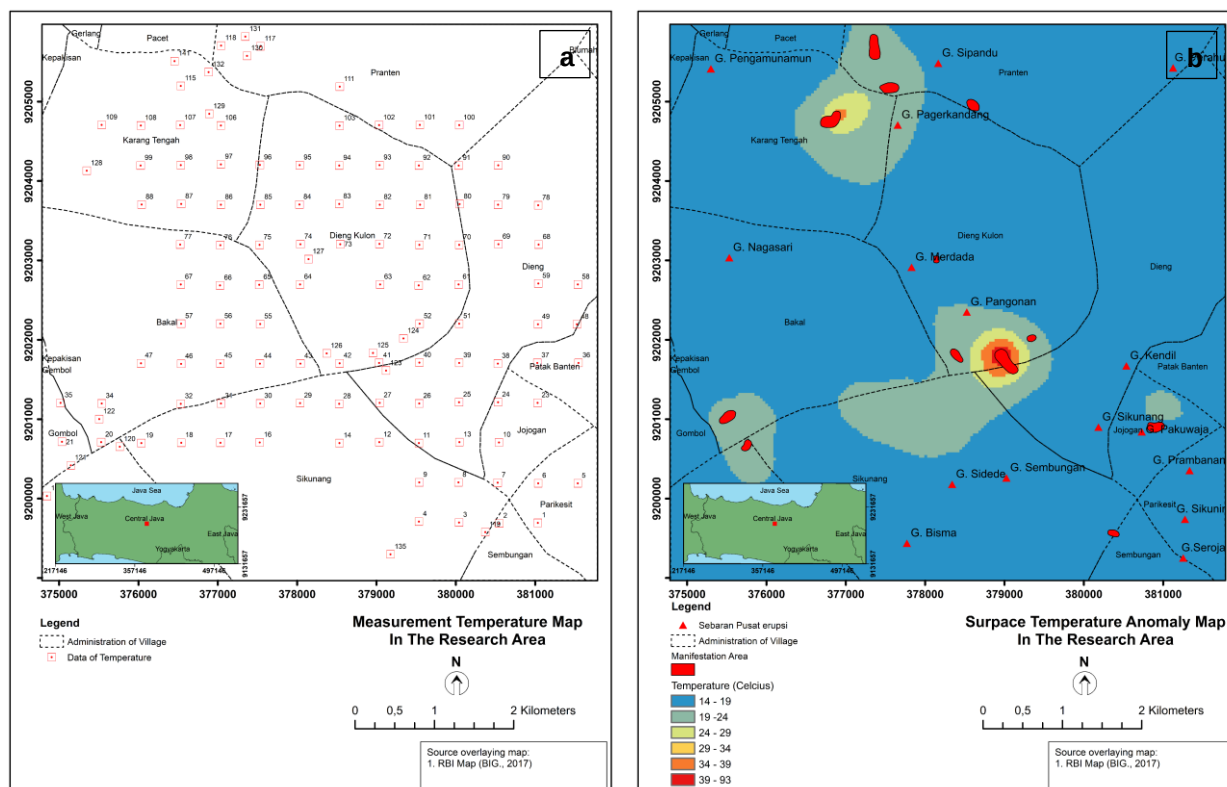


Figure 6. a) Location of measurements surface temperature, b) Map of anomalies surface temperature.

3.3. Eruption Center

Analysis of eruption centers is the analysis to determine the distribution of volcanic eruption centers to the geothermal activity. The eruption centers are analyzed to identify lithological characteristics, sources, and genesis. The Dieng volcanic complex was formed by eruption centers from different periods, where each period produced several eruption center units. The lithological characteristics of the Dieng complex are primary volcanic rocks or tephra like a tuff, tuff lapilli, and pyroclastic breccia. Moreover, there is a lithology coherent lava such as andesite lava, dacite lava, and basalt lava. The source and genesis of the Dieng volcanic complexes were built over several periods. The first period was the Old Dieng (1.09-0.92 Mya), which started with the formation of Hammock Pengamunamun, Crown Prahua, Crown Nagasari, Crown Bisma, and Hammock Sidede. The second episode was (0.46-0.37 Mya) this period constructing phase of Crown Pagerkandang, Hammock Sipandu, Crown Pangonan, and Crown Merdada. The last, young episode of the Dieng (0.27-0.07 Mya). It was started from the construction phase of Crown Kendil, Crown Pakuwaja, Hammock Prambanan, Crown Sikunir, and Crown Seroja (Figure 7).

The results of the eruption center analysis of the Dieng volcanic complex have some geothermal potential area. Such as the eruption center of Hammock Sipandu, Crown of Pagar Kandang, and Crown of Pangonan-Merdada have in the episode eruption centers of the youngest and second episode volcanic (0,43-0,07 Mya).

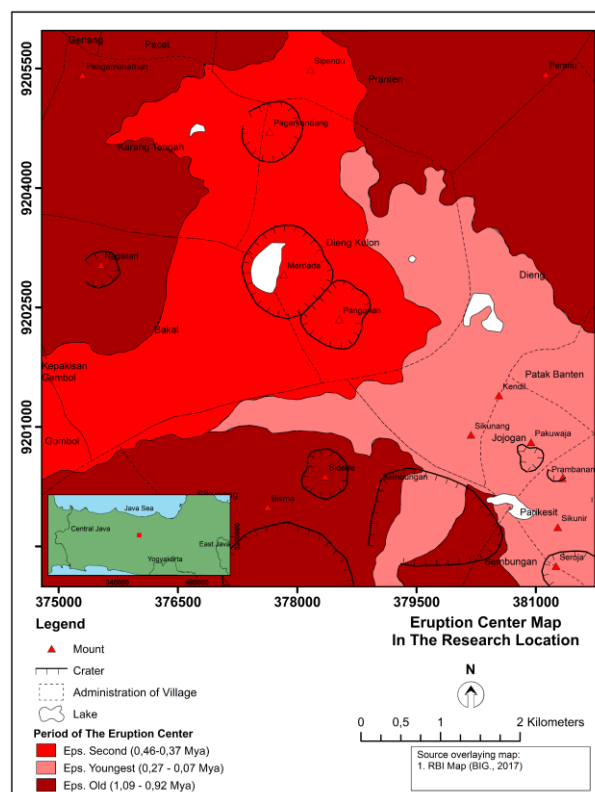


Figure 7. Eruption center of the Dieng

The assessment of the geothermal potential index using the AHP method starts with the comparison matrix among the variable and sub-variable in the research model. First, sub-variable lineament density has a CR value of 0.0586 (Table 4). The sub-variable surface temperature has a CR

Table 4. Lineament density of the comparison matrix

Variable (m)	0-250	250-500	500-750	>750	Priority
0-250	1	0.30	0.2	0.14	0.05
250-500	3	1	0.2	0.2	0.11
500-750	5	5	1	1	0.39
>750	7	5	1	1	0.43
Lambda max: 4.158 CI: 0.0527 RI: 0.90 CR: 0.0586					

Table 5. Surface temperature of the comparison matrix

Variable (°C)	14-19	19-24	24-29	23-34	34-93	Priority
14-19	1	0.33	0.33	0.14	0.14	0.04
19-24	3	1	0.33	0.2	0.20	0.08
24-29	3	3	1	0.33	0.2	0.13
23-34	7	5	3	1	1	0.35
34-93	7	5	5	1	1	0.39
Lambda max: 5.260 CI: 0.0650 RI: 1.12 CR: 0.0581						

Table 6. Eruption center of the comparison matrix

Variable	Old. Eps	Second.Eps	Youngest.Eps	Priority
Old. Eps	1	0.14	0.33	0.10
Second. Eps	7	1	1	0.51
Youngest. Eps	3	1	1	0.38
Lambda max: 3.10403 CI: 0.05202 RI: 0.58 CR: 0.0896				

Table 7. Comparison matrix between analysis variables

Variable	Surface Temperature	Lineament Density	Eruption Center	Priority
Surface Temperature	1	0.2	0.142	0.07
Lineament Density	5	1	1	0.43
Eruption Center	7	1	1	0.48
Lambda max: 3.016 CI: 0.008 RI: 0.58 CR: 0.0142				

Table 8. Integration of the hierarchy analysis

Variable	Weight	Sub-variable	Weight variable	Rank
Lineament Density	0.078	0-250	0.05	4
		250-500	0.11	3
		500-750	0.39	2
		> 750	0.43	1
		14-19	0.04	5
Surface temperature	0.435	19-24	0.08	4
		24-29	0.13	3
		23-34	0.35	2
		34-93	0.39	1
Eruption center	0.486	Second. Eps	0.51	1
		Youngest. Eps	0.38	2
		Old. Eps	0.10	3

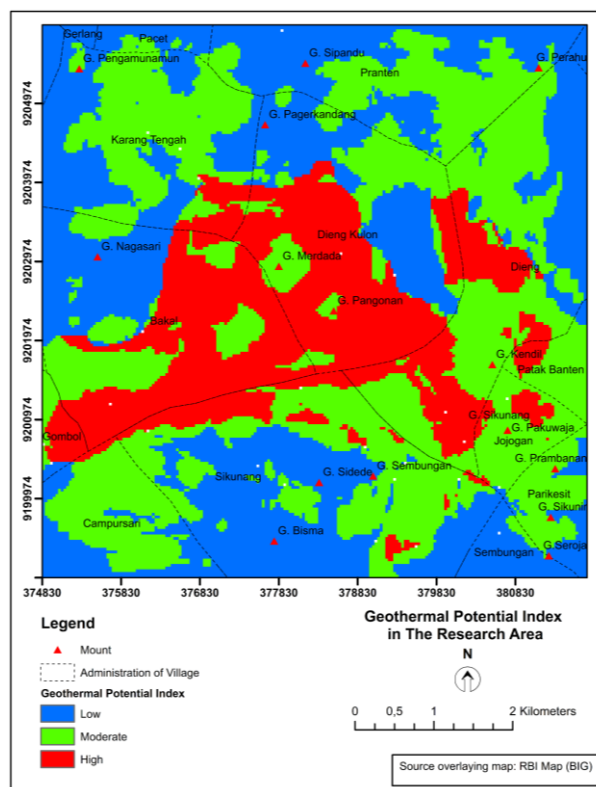
Table 9. Presentation of the geothermal potential index in the research area

No	Index	Area (Km ²)	In %
1	Low	13.9	28.6
2	Moderate	20.8	42.6
3	Height	14.0	28.7

value of 0.0581 (Table 5). Meanwhile, the sub-variable eruption center has a CR value of 0.0896 (Table 6).

The result of the comparison matrix between research variables has a value consistency ratio (CR) of 0.0142 (Table 7). That value is consistent because the ratio CR below the limit of 10% or 0.1. It means that all calculation results of the comparison matrix between variables have accepted. The value of weight composition between variables is different. Such as the surface temperature has a weight the lowest of 0.07. The lineament density has a weight high of 0.43. Meanwhile, the eruption center has a weight high of 0.48 from the comparison matrix analysis (Table 8). Based on the comparison matrix variable eruption center and lineament density are the variables of most importance.

Model geothermal potential index (GPI) map has generated by integrating variable data from the weighted overlay analysis. Based on the analysis results, the research areas have a geothermal potential index (GPI). The results of the modeling provide information that the potential index has been divided into three categories. The index potentials have a low index, medium, and high po-

**Figure 8.** Geothermal potential index in the research area resulting from analysis using the AHP method.

-tential. Where the results of the normality test show that the eruption center is the first position, second lineament density, and third surface temperature. Three variables are the most important factor in

mapping the geothermal potential index in terms of spatial information.

The percentage of GPI in the research location has shown that the low potential index a percentage of 28.6%, the moderate potential index of 42.6%, and the high potential index of 28.7% (Table 9). The geothermal potential index that high potential has been owned in the around G. Pangonan-Merdada, G. Pagerkandang, and G. Pakuwaja (Figure 8).

4. CONCLUSION

Based on the result of the analysis between the variables of the eruption center, lineament density, and surface temperature the total percentage of the geothermal potential index, the AHP method has predicted of the geothermal potential index. The index potential in the research area has been around G. Pagerkandang and G. Pangonan-Merdada with the percentage of 28.7%. The spatial information analysis can be used as the method in geothermal exploration activities. Based on the geothermal potential model, the researcher will recommend the next survey to focus on the area southeast and southwest of the Pangonan area. Meanwhile, research by Erhan & Şehnaz (2021) has similarities in determining geothermal potential. But also, the variable is used slightly differently in the modeling analysis.

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