Revealing Geothermal Potential Areas with Remote Sensing Analysis for Surface Temperature and Lineament Density: Case Study in South Bajawa, NTT, Indonesia

Dani Mardiati, Agung Setianto, Agung Harijoko
Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada
Sinduadi, Mlati, Sleman Regency, Special Region of Yogyakarta 55284
Email: dani.mardiati@mail.ugm.ac.id

Abstract. The research area is located in the Southern part of Bajawa, Ngada District, East Nusa Tenggara Province. This area has a geothermal potential and unique geological setting where many cinder cones are extending along NNW-SSE. A geothermal area usually indicated by surface manifestations that reach to the surface through geological structures. The initial stage to find out the existence of a geological structure that represented by surface lineament, and surface manifestations can be identified using satellite imagery to facilitate the exploration process in the field. The relationship between them is important to find out the potential geothermal area. Therefore, this study aims to analyze the relationship between geological lineament density and geothermal manifestations at the southern part of Bajawa based on the integration of ASTER imagery, DEM and Satellite Gravity anomalies. ASTER that consist of Visible-Near Infrared (VNIR), Shortwave Infrared (SWIR), Emissivity, and Surface Kinetic Temperature are used to identify surface geothermal manifestations. DEM imagery is used for lineament density analysis. While the satellite gravity anomalies are used to support the interpretation of geological structure in the study area. Field checking is conducted to ensure the results of images interpretation. The result of imagery analysis shows that geothermal manifestations are distributed at Nage and Mataloko areas indicated by surface kinetic temperature anomalies that reached 37.75°C and 37.85°C degrees, and rock alteration includes silicate clay minerals and quartz. High-density anomalies (>3km/km²) of geological lineament also located at Nage and Mataloko areas. Also, the analysis of Second Vertical Derivative (SVD) from satellite gravity anomalies shows that low gravity anomalies range from 0 to 0,5 mGal are found in Nage and Mataloko areas indicate the existence of geological structure in this area. The field check shows the same result where there is surface manifestation such as hot springs, fumarole, boiling mud pools, sulfur deposits, and altered rock are found at Mataloko and Nage area. The results of the interpretation of lineament density and the distribution of surface manifestations at the study area concluded that the relationship between the two is linear.

1. Introduction
The research area is located in the southern part of Bajawa, Ngada District, East Nusa Tenggara Province, Flores Island (Figure 1). It includes Wolo Bobo, Nage, and Mataloko that has great potential to be developed into a geothermal field [1]. Several geothermal manifestations have been found and separated in research areas such as hot springs, fumaroles, and altered rocks [2].
The main factor that controls the distribution of geothermal manifestations is the geological structure and it can be identified by the lineament analysis. One of the simple methods to recognize lineament is using the Fault and Fracture Density (FFD) method [3]. An area with high fault and fracture density has a high probability of the distribution of geothermal manifestations. Previous researchers researched faults and fractures at Mokai Geothermal Field, TVZ, New Zealand [4]. The result of this research is in the high FFD zone associated with the permeable zone at a deeper level that allows vertical and lateral movements of thermal water.

The research area has a unique geological setting where there are many cinder cone, young volcano and volcanic caldera in one place [5]. Also, the research area is located in a remote area. The best way to identify density lineament and the distribution of geothermal manifestation is using a remote sensing method.

Surface geothermal manifestation can be identified using ASTER imagery that consists of three subsystems, they are Visible Near Infrared (VNIR), Shortwave Infrared (SWIR) and Thermal Infrared (TIR). Then, lineament density can be recognized by DEM imagery interpretation, supported by satellite gravity anomaly to know the surface geological structure in the research area. Therefore, the aim of this study is to analyze the relation between lineament density and the distribution of geothermal manifestation based on the integration of ASTER, DEM, and satellite gravity anomaly.
3. Results and Discussion

In this study, the geology of the research area was the result of the analysis of the DEM image, supported by ASTER maps, as evidenced by direct field observations, petrography and XRD analysis on rocks.

3.1. Geomorphology

The geomorphological map aims to provide an overview of the geomorphological conditions in the research area. Geomorphological maps are made by analyzing topographic maps, DEM maps so that they can distinguish hills, valleys, terrain and slope which can be used to identify geological structures and lithological boundaries.

The division of geomorphological units is based on the classification of [8] which consists of 4 main aspects, namely morphography, morphometry, morphogenetics, and constituent material which will be associated with lithology in the research area. Also, ridge line analysis was carried out to facilitate the analysis of geomorphological unit boundaries (Figure 2).
The geomorphology map in the research area was divided into 4 units, namely volcanic caldera unit, volcanic cone unit, cinder cone complex unit, and structural hill unit (Figure 3). Figure 4 shows the geomorphological outcrop of volcanic cone unit (Inerie Volcano), structural hills, cinder cone complex unit and volcanic caldera.

---

**Figure 2.** Ridge line map of at southern part of Bajawa, Ngada District, Nusa Tenggara Timur Province to support delineation of geomorphological and geological map.

**Figure 3.** Geomorphology map at research area consist of 4 unit (volcanic caldera unit, volcanic cone unit, cinder cone complex unit, structural hill unit).
3.2. Lithology

Based on the results of the interpretation of DEM imagery, regional geological maps, geological maps of the research location in previous studies, and direct observations in the field produced several rock groups that were interpreted as lithological units.

In general, the lithology units in the research area are divided into 6 namely Inerie lava and pyroclastic units, lava and pyroclastic units Wolo Bobo, Mataloko lava and pyroclastic units, Siuturo lava and pyroclastic units, Aimere lava and pyroclastic units, and Waebela lava and pyroclastic units (Figure 5). The unit name is the name of each volcano which is the source of the lithology unit and the name of the location where the sediment is located.

3.2.1 Inerie Lava and Pyroclastic Unit. This unit is centered on Mount Inerie and is the youngest unit in the research area. This unit is composed of basaltic lava deposits, lahar with 12 meters thickness and loose material volcanic that located in the slope of Mount Inerie. The age of this unit is Pleistocene.

Figure 6 shows the outcrop of this unit in the field. It is lahar deposits that consist of a basaltic fragment from the Inerie Volcano. The petrographic section shows that the phenocryst of the fragment consists of plagioclase, orthopyroxene, clinopyroxene, and opaque minerals.

---

**Figure 4.** Geomorphological outcrop shows volcanic cone unit (Inerie Volcano), structural hills, cinder cone complex unit and volcanic caldera at southern part of Bajawa, Ngada District, Nusa Tenggara Timur Province.
Figure 5. Geological map at southern part of Bajawa, Ngada District, Nusa Tenggara Timur Province that consist of 6 lithological unit and distribution of geothermal manifestations.

Figure 6. (left) Outcrop and petrographic section of Inerie Volcano; (right) outcrop and petrographic section of Wolo Bobo lava and pyroclastics unit.

3.2.2 Wolo Bobo Lava and Pyroclastic Unit. This unit is a product of the Wolo Bobo cone complex. There are at least 9 cinder cones that compose Wolo Bobo lava deposits and pyroclastic deposits. This unit is composed of massive lava and pyroclastic deposits. Based on field observations and laboratory analysis, the type of lava is andesite. Whereas the pyroclastic deposits contain andesite rock fragments. This rock unit is Pleistocene.

Figure 6 shows the outcrop of this unit in the field. It is lava that consists of andesite rock. The petrographic section shows that phenocryst of the fragment consists of plagioclase, orthopyroxene, clinopyroxene, and opaque minerals.
3.2.3 Mataloko Lava and Pyroclastic Unit. This unit is the most widespread in the research location, which is to the east of the research location. In this unit, more than 30 cylindrical cones are forming a straight line northwest-southeast direction. Composed of andesite lava, lava, and other pyroclastic materials.

3.2.4 Siutoro Lava and Pyroclastic Unit. This rock unit is located in the southeast of the research area or on the east of the Nage Caldera. This unit is composed of andesite lava and pyroclastic deposits.

3.2.5 Aimere Lava and Pyroclastic Unit. This unit is the unit located in the northwest of the research location and is located just north of Mount Inerie. The distribution is quite extensive.

3.2.6 Waebela Lava and Pyroclastic Unit. This unit is located in the south of the research area and is the oldest rock unit in the research area. The outcrop of this unit is found in the Nage Caldera.

3.3. Distribution of Lineament Density
The direction of lineament and geological structure that developed in the research area resulted from the integration of DEM image analysis, gravity anomalies of satellite image analysis, and geological structure of the Ruteng regional geology map by [6].

Lineament density or fault and fracture density defined as the total length of lineament per unit area [9]. The lineament density in the research area was divided into a 1 km grid system. The total length of lineaments inside each grid (in km) was measured and the result was used to compute a representative value of FFD (in km/km²) at the center of the grid [4]. The lineament density value in research area has range from 0-3.9 km/km² and was classified into 3 class namely high (>3 km/km²), medium (2.01-3 km/km²), and low density (0-2 km/km²).

At Te Kopia, for example, the geothermal reservoir is associated with FFD ≥3 km/km² [9]. High lineament density anomalies in the research area are distributed in Nage, Nenowea, Golewa Selatan, Ngadabawa, Mataloko and west of Inerie Volcano.

To find out the direction of the lineament, lineament data plotting is conducted in the rose diagram using Rockworks15 software (Figure 7). The rose diagram calculation method is conducted based on the length of the line. The longer the line will give a higher weight to the calculation. The direction of lineament in the research area generally forms 2 dominant directions namely NE-SW (northeast-southwest) and NW-SE (northwest-southeast) direction. Lineament density shown in Figure 8.

3.4. Surface Thermal Anomaly
Thermal anomalies in the research area are the result of the integration of ASTER surface emissivity and surface kinetic temperature. Thermal anomalies of the two maps indicate the presence of geothermal manifestations and ground checking is conducted to ensure the results of ASTER image interpretation. Surface kinetic temperature of Inerie Volcano shown in Figure 9.

3.5. Thermal Anomaly of Inerie Volcano
Mount Inerie is one of the active volcanoes in the Ngada Regency, Flores, NTT. The thermal anomaly on the Inerie Volcano is located at the top of the volcano. The temperature anomaly at the top reaches 313.3K, equivalent to 40.15°C. Based on its location, a thermal anomaly at Inerie Volcano suggested originate from the center of the volcanic neck so that the area has a hotter temperature than the surrounding area.
Figure 7. Lineament map shows 2 lineament directions (NW-SE and NE-SW) at southern part of Bajawa, Ngada District, Nusa Tenggara Timur Province.

Figure 8. Lineament density map shows 3 classes, high density (3.01-3.09 km/km²), medium density (2.01-3 km/km²), and low density (0-2 km/km²) at southern part of Bajawa, Ngada District, Nusa Tenggara Timur Province.
Figure 9. Surface kinetic temperature anomaly at Inerie Volcano shows thermal anomaly reach 313.3K.

3.6. Thermal Anomaly of Nage Area

Based on surface kinetic temperature, a thermal anomaly at the Nage (Figure 10) area has a maximum temperature of 310.9 K or equivalent to 37.75°C. The existence of area with higher temperature compared to the surrounding area gives an indication of the existence of heat source originating from the earth.

Based on ground checking, areas that have surface kinetic temperature anomalies at Nage found several manifestations. There are 3 vents of hot springs with temperature 76.4°C, 75.4°C, dan 76.3°C; sulfur deposits; and altered rock about 60 x 500 m at the side of Wae Bana River.

Figure 10. Surface kinetic temperature anomaly at Nage area shows thermal anomaly reach 310.9 K.
3.7. Thermal Anomaly of Mataloko Area

The third thermal anomaly at the research area was found at Mataloko with the maximum temperature reach 311 K or equivalent to 37.85°C. Based on ground checking, geothermal manifestations such as hot springs, hot mud pools, fumaroles, and alteration minerals are found in Mataloko. Based on the analysis of the surface kinetic temperature map (Figure 11) and the direct appearance in the field, it shows that the surface kinetic temperature map is useful as an initial indication of the existence of geothermal manifestations in an area.

![Surface kinetic temperature map of Mataloko area.](image)

**Figure 11.** Surface kinetic temperature anomaly at Nage area shows thermal anomaly reach 311 K.

![Geothermal manifestations at Nage and Mataloko areas.](image)

**Figure 12.** (left) geothermal manifestations (hot springs, sulphur deposits and altered rock) at Nage area; (right) geothermal manifestations (boiling mud pools, fumarole, and altered rock) at Mataloko area.

3.8. Rock Alteration

Alteration at the research area is the result of ASTER Image data integration and proven by direct field observation (Figures 12) and data analysis in the laboratory (Figure 13 and 14). The image of ASTER VNIR-SWIR shows the presence of silicate clay minerals in the research area. While the image of ASTER TIR shows the presence of abundant quartz minerals.
The distribution of silicate clay minerals in 3 locations that have surface kinetic temperature anomalies, at Inerie Volcano, Nage, and Mataloko. The presence of these alterations is characterized by bright colors. The brighter, the composition of the rock alteration has higher abundance, whereas the darker, the composition of rock alteration has a lower abundance. Also, spectral analysis of quartz minerals was carried out in the study area using the image of ASTER TIR (Thermal Infrared).

Analysis of altered rocks was also carried out using XRD (X-Ray Diffraction) analysis to ensure the result of image interpretation. XRD analysis was carried out in 5 locations, namely in Nage (DM 10), and Mataloko (DM 11, DM 12-2, DM 12-3). The results of the XRD analysis that have been carried out at the research location are shown in Table 1.

![Figure 13. Clay silicate abundance at southern part of Bajawa, Ngada District, NTT Province.](image-url)

**Table 1.** The result of X-Ray Diffraction analysis.

| No. | Sample code | Minerals                           |
|-----|-------------|------------------------------------|
| 1   | DM 10       | Cristoballite, tridymite, quartz   |
| 2   | DM 11       | Cristoballite, quartz              |
| 3   | DM 12-2     | Tridymite, calcite                 |
| 4   | DM 12-3 (1) | tridymite, quartz, cristoballite   |
| 5   | DM 12-3 (2) | Tridymite, cristoballite           |
3.9. Relation between Lineament Density and Distribution of Geothermal Manifestation in Research Area

The surface kinetic temperature map and ground checking show thermal anomalies found at Nage and Mataloko areas which indicate the distribution of geothermal manifestations.

Manifestations that located at Nage consist of hot springs, sulfur deposits, and altered rocks. After being overlapped with lineament density maps at the research area, geothermal manifestations at the Nage area are located at high lineament density.

Whereas the geothermal manifestations at the Mataloko area are more varied consisting of hot mud pools, fumaroles, and altered rocks. The overlap results with lineament density maps (Figure 15) at the research area, geothermal manifestations in Mataloko are also located at high lineament density.

Also, the subsurface structure can be analyzed using satellite gravity anomalies that have been processed into residual anomaly maps using Second Vertical Derivative (SVD) filter. This SVD filter is useful for generating superficial or local sources of gravitational anomalies. This method is conducted by reducing Bouguer anomalies complete with regional Bouguer anomalies (Figure 16). In this research, the SVD filter was performed using [10] calculations by entering the following values as the filter (Table 2).

![Figure 14. Quartz abundance at southern part of Bajawa, Ngada District, NTT Province.](image)
Table 2. Input value for Second Vertical Derivative (SVD) calculation [10]

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 0.00  | -0.0833 | 0.00  | -0.0833 | 0.00  |
| -0.0833 | -0.0667 | -0.0334 | -0.0667 | -0.0833 |
| 0.00  | -0.0334 | 1.0668 | -0.0334 | 0.00  |
| -0.0833 | -0.0667 | -0.0334 | -0.0667 | -0.0833 |
| 0.00  | -0.0833 | 0.00  | -0.0833 | 0.00  |

Figure 15. Lineament density shows 3 classes and the distribution of geothermal manifestations at southern part of Bajawa, Ngada District, Nusa Tenggara Timur Province.

Figure 16. (a) Complete bouguer anomaly; (b) regional gravity anomaly of research area.
The range of gravity values at research are ranged from -8 to 5 mGal (Figure 17). Where high anomalies are indicated with ranges ranging from 0.5 to 5 mGal the map is shown in orange to red. Medium anomalies range from 0.5 to -2.5 mGal indicated by green color. While the low anomaly has a range of -2.5 to -8 mGal which is shown in blue to purple. Low and high anomalous contrasts drastically indicate the presence of geological structures and the presence of intrusions below the surface. Residual gravity anomaly shown in Figure 18.

A high gravity anomaly in the form of a flat contour (circular) is in the southern part of the research location (Caldera Nage) with a value range of 0.5 - 5 mGal. The anomaly may be caused by the presence of rocks with a density greater than the surrounding area or usually, is igneous rock intrusion.

Based on the analysis of lineament density, gravity anomalies of satellite images and the distribution of manifestations at the research area indicate that high lineament density is not always found to be geothermal manifestations. However, geothermal manifestations in the research area are always found at high lineament density value (>3km/km²). This means that the lineament on the surface, especially in areas with geothermal potential, can indicate the existence of geothermal manifestations on the surface. This is because these lines (especially valley lineament) reflects a weak zone on the surface of the earth where the weak zone is usually associated with the location of the geological structures. Whereas the geological structure is the escape route for hydrothermal fluid from the earth to the surface of the earth.

Figure 17. Second Vertical Derivative (SVD) map of research area.
Figure 18. Residual gravity anomaly, lineament geology and distribution of geothermal manifestations map shows the relationship among them.

4. Conclusion
Based on the results of research and discussion, conclusions can be drawn as follows:

Geothermal manifestations are distributed at several points in the research area including hot springs, sulfur deposits, rock alteration in the Nage area; hot mud pools, fumaroles, warm ground and altered rock in the Mataloko area.

Lineament density in research area is divided into 3, which are high (3.01-3.9 km/km²), medium (2.01-3 km/km²), and low density (0-2 km/km²). High lineaments density is distributed at Nage, Mataloko, Aimere, Menowea, and Golewa Selatan. Contrast values of low and high gravity anomalies indicate the presence of geological structures found at Nage and Mataloko area. High gravity anomaly found at Nage suggests as the high-density rock that can act as a thermal source at the Nage area.

The relationship between geothermal manifestations and lineament density is: geothermal manifestations at research area are always found at high lineament density value (>3km/km²) but high lineament density at the research area is not always found to be geothermal manifestations.

References
[1] Akasako H, Matsuda K, Tagomori K, Koseki T, Takahashi H and Dwipa S 2002 Conceptual models for geothermal system in the Wolo Bobo, Nage, Mataloko Fields, Bajawa Area, Central Flores, Indonesia Bulletin of the Geological Survey of Japan 53 375-387
[2] Takahashi M, Urai M, Yasukawa K, Muraoka H, Madsuda K, Akasako H, Koseki T, Hisatani K, Kusnadi D, Sulaeman B and Nasution A 2002 Geochemical characteristic of hot spring water in Bajawa Area, Central Flores, Indonesia Bulletin of Geological Survey of Japan 53 183-199
[3] Suryantini and Wibowo H H 2010 Application of Fault and Fracture Density (FFD) method for geothermal exploration in non-volcanic geothermal system: a case study in Sulawesi-Indonesia Proceedings World Geothermal Congress 2010
[4] Soengkono S 2000 Assesment of fault and fractures at the Mokai Geothermal Field, Taupo Volcanic Zone, New Zealand Proceeding World Geothermal Congress 2010 1771-1776

[5] Muraoka H, Nasution A, Urai M, Takahashi M, Takashima I, Simanjuntak J, Sundhoro H, Aswin D, Nahlohy F, Sitorus K, Takahashi H and Koseki T 2002 Tectonic, volcanic and stratigraphic geologi of the Bajawa Geothermal Field, Central Flores, Indonesia Bulletin of Geological Survey of Japan 53 109-138

[6] Koesoemadinata S, Noya Y and Kadarisman D 1994 Peta geologi lembar Ruteng, Nusa Tenggara Skala 1:250.000 Pusat Penelitian dan Pengembangan Geologi

[7] Sehah F A K 2012 Pemanfaatan data anomali gravitasi citra GEOSAT dan ERS-1 satellite untuk memodelkan struktur geologi cekungan Bentarsari Brebes Indonesian Journal of Applied Physics 2 184

[8] van Zuidam R A 1985 Aerial photo interpretation in terrain analysis and geomorphologic mapping Netherlands: Smith

[9] Soengkono S 1999 Te Kopia geothermal system (New Zealand) – The relationship between its structure and extend Geothermics 28 767-784

[10] Elkins T A 1951 The second derivative method of gravity interpretation Geophysics 16 29-50