Identification of Permeability Level by using Fault Fracture Density Analysis and Landsat 8 OLI at Ulubelu Geothermal Area

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Abstract. Ulubelu geothermal field is located approximately 125 km at the west of Bandar Lampung, Lampung Province. Currently, the Ulubelu geothermal prospect has been developed as a geothermal power plant with 220 MW installed capacity. Ulubelu geothermal field began to operate since 2012 with the first capacity of 3x55 MW which has a temperature of 265°C with 1,160 kg/kJ average enthalpy and developed as water dominated system with single flash system technology. This research analyzes fault fracture density in the area to study the area which can potentially have high permeability or fracture by using remote sensing data (digital elevation map) to delineate the lineaments which can be observed at Ulubelu and surrounding. This research is also used Landsat 8 OLI data to determine the vegetation level of the Ulubelu area. The result of the analysis shows that there are three potential areas to be the recharge area, west of Mt. Pematang Sulah, west of Mt. Rendingan, and north of Mt. Rendingan. The recharge area should be preserved to maintain the geothermal system in the Ulubelu area.

1. Introduction
Ulubelu geothermal field is a volcanic-hydrothermal system which is located in Lampung Province, 125 km to the west of Bandar Lampung city. This liquid dominated system is already developed since 2012 with 220 MW installed capacity and the reservoir has a temperature of 265°C [1]. The average enthalpy produce is 1,160 kg/kJ with single flash system technology [2]. Ulubelu geothermal field is contributing to about 25% of Lampung electrification [3]. In their production phase, PT. PGE should notice the environmental aspect so the steam production is not excess the input to the reservoir to maintain the system so the geothermal system in Ulubelu fulfills the jargon of geothermal is sustainable energy.

In recent days, remote sensing data has been widely used in geothermal exploration, especially for preliminary exploration [4–6]. Remote sensing is used because it provides data that ease the fieldwork because it can reach areas that cannot be reached by humans. In geothermal exploration, remote sensing is usually used to analyze the morphology of the study area [7], mineral mapping [5,8–10], lineament analysis [11,12], thermal anomalies [13,14], etc. This circumstance makes geoscientists have a framework before conducting ground truth to the field.

This study uses remote sensing data in the form of a national digital elevation model (DEMNAS) and Landsat 8 OLI which aims to determine the level of permeability around the Ulubelu geothermal area. DEMNAS data will be processed later to produce a fault fracture density (FFD) map that gives a relative value of density at each place that reflects the level of relative permeability. Landsat 8 OLI data will be processed and produce a true-color image and normalized difference vegetation index (NDVI). Then the results of this analysis can find out the possible area as a recharge area and need to be
maintained so that meteoric water can infiltrate into the geothermal reservoir properly without interruption and make the existing geothermal system in Ulubelu sustainable.

2. Geological Setting

2.1. Morphology
Generally, the morphology of the study area is surrounded by hills, ridges and composite volcanoes with presence of depression/basin zones in the middle of the study area (Ulubelu area). The morphology of the study area is clearly seen by using National Digital Elevation Model (DEMNAS) in Figure 1. The DEMNAS image is seen from an altitude of 75° with the azimuth of 45°. At least there are three morphologies that show circular feature and it is interpreted as recent craters or old craters of volcanoes. The first is located at the top of Mt. Rendingan with the direction of the crater opening to the southeast with a diameter of about 2 km. Secondly, it is located on Mt. Pematang Sulah, which leaves a slightly circular feature with a length of about 4 km that opens to the east. Then the third is located around Mt. Way Panas with the direction of opening to the east. In the middle of the study area, there is a depression zone (Ulubelu area) which is the working area of PT. PGE forms a basin and has been filled with water to form Danau Hijau Lake which is thought to be an old crater lake. In the depressive zone, two hills were interpreted to be formed due to younger igneous rock intrusion.

Based on the results of the rosette diagram analysis of lineament extraction using DEMNAS imagery, that lineaments in the study area are predominantly northeast-southwest (Figure 1). This could indicate that the geothermal system in this area is no longer dominated by the Great Sumatran Fault system that is trending northwest-southeast [1,15].

![Figure 1. Morphology of Ulubelu geothermal area.](image)

2.2. Rock Formation and Geological Structure
The study area consists of several rock formations from older to younger, respectively [16]: Hulusimpang Formation (Tomh), late Oligocene, consist of volcanic breccias, andesitic to basaltic lavas
and tuffs, hydrothermally altered with sulfide mineral-bearing quartz vein. Tmgr is a granite intrusion that intruded in Middle Miocene. Semung Formation (QTse) is a Pleistocene sedimentary rock consist of conglomeratic sandstone, sandstone, and claystone. Mostly the research area is covered by Quaternary volcanic rock products from Mt. Rendingan and Mt. Tanggamus which consist of andesitic-basaltic breccias, lava, and tuff. And lastly, the unconsolidated alluvium that located in the southwestern part of the research area which consists of various sediment sizes.

The geological structure of the research area consists of several faults that trending relatively northeast-southwest and northwest-southeast. Also, three old craters can be seen on top of Mt. Rendingan, Mt. Pematang Sulah, and Mt. Way Panas, respectively.

**Figure 2.** Geology of the Ulubelu Geothermal area.

### 3. Material and Methods

This research was conducted using input data in the form of a National digital elevation map (DEMNAS) which was downloaded from the page [http://tides.big.go.id/DEMNAS/](http://tides.big.go.id/DEMNAS/). DEMNAS data is used because it provides a detailed morphological image so that lineament extraction in the study area provides better results than DEM data downloaded from other places (e.g. CGIARCSI, earthexplorer, etc.). The National DEM was built from several data sources including IFSAR data (5m resolution), TERRASAR-X (5m resolution) and ALOS PALSAR (11.25m resolution), by adding stereo-plotting Masspoint data, the spatial resolution of DEMNAS is 0.27-arcsecond, using vertical datum EGM2008 [17]. DEMNAS data processing is carried out using Geomatica 2015 software to extract lineament automatically by using the parameters in **Figure 3**. The data processing flowchart is summarized in **Figure 4**. Automatic lineament extraction on Geomatica 2015 utilizes the Librarian Algorithm - Lineament Extraction function. In this article, the authors do not discuss the algorithm used by the software in extracting the lineament because the author only needs results from the lineament that has been extracted. We conclude that the lineament extraction function at Geomatica 2015 has provided valid results which considering of geological condition so that the data can be used and further analyzed. The results of the lineament extraction are shown in **Figure 1**.
The fault fracture density map requires straight-line data input in the form of a single line, while the straight-line extraction results from Geomatica 2015 is a polyline, so that the lineament extracted will be processed again using ArcGIS software by changing the lineament into a single line. This is done by using the split lineament tool in the ArcGIS toolbox. Split lineament produces 7,163 single-line straight lines with varying lengths (see Figure 1). The next stage is making line density maps using the density map tool available in the ArcGIS toolbox. The map will be further analyzed and interpreted to see the level of permeability in the study area.

In addition, the lineament that has been produced is also used to make a rosette diagram to see the direction of the lineament distribution. The diagram is made by calculating the length of the lineament in a particular direction compared to the total lineament that exists. For example, for lineament in the 0-10° direction, the lineament calculation will be followed by this equation:

\[ 0 - 10° = \frac{\sum \text{Length of lineament in trend } 0-10°}{\sum \text{Total of all lineament length}} \times 100\% \]  

(1)
The summary of the calculation will be used to make a rosette diagram, which is shown in Figure 1. Generally, the distribution of lineament in the study area is trending northeast-southwest.

Moreover, this study also uses Landsat 8 OLI data to interpret the urban activities and the distribution of vegetation using the NDVI method. Table 1 presents the specifications of the Landsat data used in this study. Landsat 8 OLI data processing begins by performing radiometric calibration to convert the digital number (DN) values into reflectance values. Then the atmospheric correction process is done to get a better image. This data will be used to produce a true color composite map by combining the RGB band in 432 band, false-color composite by combining RGB 543.

On the other hand, Landsat 8 OLI data is also used to produce an NDVI map to determine the distribution of vegetation. NDVI is widely used for estimating vegetation density and its health and vigor [9]. It is expressed as [18]:

\[
\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}
\]

(2)

Table 1. Specifications of the Landsat 8 OLI data.

| Satellite | Sensor | Path | Row | Year | Resolution (m) | Wavelength (μm) |
|-----------|--------|------|-----|------|----------------|-----------------|
| Landsat-8 | OLI    | 124  | 64  | 2014 | 30             | Band 1: 0.435–0.451 |
|           |        |      |     |      | 30             | Band 2: 0.452–0.512 |
|           |        |      |     |      | 30             | Band 3: 0.533–0.590 |
|           |        |      |     |      | 30             | Band 4: 0.636–0.673 |
|           |        |      |     |      | 30             | Band 5: 0.851–0.879 |
|           |        |      |     |      | 30             | Band 6: 1.566–1.651 |
|           |        |      |     |      | 30             | Band 7: 2.107–2.294 |
|           |        |      | 15  |      | 30             | Band 8: 0.503–0.676 |
|           |        |      | 30  |      |                | Band 9: 1.363–1.384 |

4. Result and Discussion
Based on the results of lineament data processing using ArcGIS, a fault fracture density map can be generated, which is shown in Figure 5. It can be seen that three areas have relatively high-density values in the study area, namely north of Mt. Pematang Sulah (Area 1), west of Mt. Rendingan (Area 2), and north of Mt. Rendingan (Area 3). The high value of lineament density can be correlated with the relatively high level of permeability in the area. So, it is estimated, the part that has a high density is an area that is relatively more permeable compared to an area that has a lower value, and that area is interpreted as a relatively good for recharge area. This interpretation requires ground truth to the field to prove that the area indeed has good permeability, which expresses as the geological structure in the field, such as fracture, fault, fold, etc.
Figure 5. Fault fracture density map of the Ulubelu geothermal area.

Landsat 8 OLI data is processed to produce three images that can be used to determine the vegetation area. Recharge areas can be able to absorb water below the surface better if the area is a densely vegetated because water will tend to flow slower on the surface (reducing runoff or surface flow) [19]. Besides, the flow of water on the surface is also influenced by the size of trees, the taller, and the bigger the tree, the better the ability of the tree to hold water through. Therefore, so that the sustainability of the geothermal system in Ulubelu can be appropriately maintained, the vegetation in the recharge area must also be maintained.

From the NDVI map (Figure 6), Area 1 and Area 3 are areas that have relatively sparse vegetation compared to Area 2, which is dense vegetation (note that the red color is highly dense vegetation, green is medium, and blue to purple is low vegetation). From the TCC map (Figure 7) and FCC (Figure 8), Area 1 and Area 3 are areas that are quite dense with population (light blue on the FCC map indicates urban activity such as roads, settlements, barren land), while the level of vegetation on this area is relatively poor (marked in light green on the TCC map) which indicates that the vegetation in the area is vegetation of small trees/grasses. Seen from the combination of FFD, NDVI, TCC, and FCC, Area 2 is the ideal area as a recharge area because it has good permeability, dense vegetation, and low urban activity. So that the sustainability of the Ulubelu geothermal system can be maintained, the planting of large trees is strongly recommended in areas 1 and 3 so that water can infiltrate well in the area.
Figure 6. Normalized difference vegetation index map of Ulubelu area.

Figure 7. True color composite map RGB 432 of Ulubelu area. The red area is a high-density area.
Figure 8. False-color composite map RGB 543 of the Ulubelu area. The black area is a high-density area.

5. Conclusion
Three areas show the high-density value that is interpreted has relatively good permeability and is more likely to be the better area for the water recharge, which is north of Mt. Pematang Sulah, west of Mt. Rendingan, and north of Mt. Rendingan. From these three areas, the west of the Mt. Rendingan area is the ideal area to be the recharge area because it has good permeability, dense vegetation, and less urban. Reforestation is needed in the west of Mt. Pematang Sulah and north of Mt. Rendingan to increase the water catchment level.

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