Application of Remote Sensing for Determination of Power Plant Area: Case Study of Lumut Balai, South Sumatra

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Abstract. Subduction zone located beneath Sumatra, Indonesia causes the formation of volcanic sequences, which can be associated with the potential of geothermal energy. One of them is Lumut Balai area in South Sumatra. A study of using remote sensing method was conducted as one of the preliminary methods to find out the geothermal potential in the Lumut Balai area. In this case, an analysis of regional geology maps, Landsat 8 OLI / TIRS, and digital elevation model (DEM) was carried out. The geothermal potential is obtained based on a combination of anomalies in land surface temperature (LST), the normalized difference vegetation index (NDVI), and distribution of alteration zones. The analysis of NDVI result shows the Lumut Balai area dominated by mostly moderate to high level of vegetation density up to 0.88. Whereas, the LST result shows the maximum value, which is 40.3°C located at the residential area in the north and the open land in the northwest of Lumut Balai. The correlation between the results of LST and NDVI has been shown in geothermal surface manifestations, that have vegetation less than 0.88 while the temperatures show a higher value up to 40°C than the surrounding its area. While the results of the DEM analysis provide topographic information, the slope in the study area used to determine the area for development of power plant. The power plant more likely to be located in the southwest and northeast of Lumut Balai where it has flat terrain and not in the near-fault area.

1. Introduction
Lumut Balai area located in Ogan Komering Ulu, South Sumatra Province. Lumut Balai is one of the geothermal projects that run by PT. Pertamina Geothermal Energy. The status of Lumut Balai field has now entered the stage of exploitation and planned to install of 2×55 MWe geothermal power plant capacities [1].

The Lumut Balai prospect covers the area of Mt. Lumut, Mt. Balai, part of the Mt. Ringgit, and part of the Mt. Pandan. The morphology of this area forms an eroded volcanic mountain complex which is the strongest plateau known as the Semendo Plateau [2]. Manifestations, as well as an active fumarole field, is present in the Mt. Lumut. This field surrounded by steaming ground and acid surface alteration (Penindayan field). Another group of manifestations occurs within the NE foothills of Balai Volcano where boiling springs (Ogan Kanan group) discharge near neutral-pH sodium chloride water (estimated mass flow rate of about 300 kg/s) and sinter deposit [3].

Remote sensing is not only used to map objects on the earth’s surface, but it can also reveal earth phenomena that cannot be directly captured by the human eye. For example, by using certain algorithms, remote sensing can offer a spatial distribution of surface temperature values in some areas,
distinguish plants affected by diseases and healthy plants in an agricultural area [4]. The initial stage of geothermal exploration can be done using remote sensing methods and geographic information systems to utilize and assess the geothermal location. The remote sensing method used is by applying the application to the band channel on Landsat 8 imagery and then interpreting it in the form of a map so that geothermal prospecting developers can easily access locations included in geothermal developers [5]. Results of surface spectral characteristic, temperature anomalies, and several parameters will indicate the existence of geothermal potential. In addition, topographic maps and recommendations for power plant locations were made and applied to determine the proper geothermal construction location.

2. Data and Methodology

2.1. Data

The study used Landsat 8 data with path/row 125/63 in the southern hemisphere 48 with the coordinate system of Universal Transverse Mercator (UTM) which obtained from the USGS Explorer and topographic data from http://tanahair.indonesia.go.id/. The Landsat 8 image was processed using ENVI 5.1 and ArcGIS 10.2 software to obtain a map of surface temperature, vegetation index, composite band, and land slope. One of the prospects of geothermal manifestations is the presence of an anomaly from the processing of surface temperatures compared to the surrounding area.

2.2. Methodology

A composite map displays a color image or composite image, it takes at least three layers at once which are used to fill the red, green and blue channels. For this study, the true color consists of band 4, 3, and 2 which fill the red, green, and blue channel sequentially. The false-color consists of band 5, 6, and 7 which fill the red, green, and blue channels. In addition, a composite map was created by combination band of 4/2, 6/7 and 5. Band 8, which is a panchromatic band used to obtain clearer information by sharpening process with a spatial resolution of 15×15 meters on the panchromatic channel.

The Normalized Difference Vegetation Index (NDVI) is a method to measure the rate of vegetation by comparing spectral between near-infrared waves and red waves. In Landsat 8, NIR is in band 5 while RED is in band 4. This band value is still in the form of a digital number so each band 4 and band 5 must be calibrated into Top of Atmosphere (TOA) reflectance as:

$$P_\lambda' = M_p \times Q_{\text{cal}} + A_p$$

where $Q_{\text{cal}}$ is a pixel value in the digital number, $M_p$ is a band-specific multiplicative rescaling factor, $A_p$ is a band-specific additive rescaling factor, and $P_\lambda'$ is a TOA reflectance value that has not corrected with sun's elevation angle. Therefore to get a $P_\lambda$ that has corrected with the sun's elevation angle then, the below equation is applied:

$$P_\lambda = \frac{P_\lambda'}{\sin(\theta_{SE})}$$

($\theta_{SE}$) is local sun elevation angle. The value of ($\theta_{SE}$) can be seen from the image metadata file. The NDVI value can be obtained from:

$$\text{NDVI} = \frac{\text{NIR}-\text{RED}}{\text{NIR}+\text{RED}}$$

To identify the surface temperature, the wave that will be used is the thermal wave. In Landsat 8, a band that will be used is band 10 which has a wavelength of 10.60 – 11.19 μm. The first step is to calibrate the band 10 in the form of a digital number into the spectral radians or TOA radiance by:
\[ L_\lambda' = M_L \times Q_{\text{cal}} + A_L \]  

(4)

Where \( L_\lambda' \) is the spectral value of radians (W / (m² × sr × μm)), \( Q_{\text{cal}} \) is the pixel value in the digital number, \( M_L \) is a multiplicative rescaling factor, and \( A_L \) is additive rescaling factor. Next is the atmospheric correction before calculating the temperature with the equation [6]:

\[ L_\lambda = \frac{L_\lambda' - L_u}{1 - e^{-\tau}} - L_d \]  

(5)

The value of \( L_\lambda \) is a corrected spectral value, \( e \) is the emissivity obtained from equation (8), \( \tau \) is the transmittance value, \( L_u \) is upwelling radiance, and \( L_d \) is downwelling radiance. The value of these variables is obtained from the web https://atmcorr.gsfc.nasa.gov/, with first enter recording date and time information image, and the center of latitude and longitude coordinates of the image used.

\[ T = \left( \frac{K_2}{\ln \left( \frac{K_1}{1 + 1} \right)} \right) - 272.15 \]  

(6)

The value of \( T \) is the temperature value (°C) recorded by the sensor. \( K_1 \) and \( K_2 \) are thermal conversion constants that can be seen from the image metadata file. While the value of surface temperature is corrected to the value of emissivity to reduce the error in estimating the value of LST. To get the surface emissivity value, the alternative that can be used is to use the NDVI value that has been obtained from equation (3).

\[ PV = \left( \frac{\text{NDVI} - \text{NDVI}_{\text{min}}}{\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}}} \right)^2 \]  

(7)

Where \( PV \) is the value of the proportion or fraction of vegetation. To obtain \( e \), which is surface emissivity values, then the equation (8) is applied:

\[ e = m \times PV + n \]  

(8)

The estimation of the value of LST is done by inversion of Planck function. LST is the value of surface temperature. The LST value is calculated with:

\[ \text{LST} = \frac{T}{1 + \left( \frac{W \cdot T}{P} \right) \ln(e)} \]  

(9)

\( T \) is the value of brightness temperature obtained from equation (6), the value of \( W \) is the radiant wavelength emitted, in this case, \( W \) is the average value of the band wavelength 10. While the value of \( P \) is the result of the calculation of \( h \times c / s \). Where \( h \) is the Planck constant (6.626 x 10⁻³⁴ Js), \( c \) is the value of the speed of light (2.998 x 10⁸ m / s) and \( s \) is the Boltzmann constant value (1.38 x 10⁻²³ J / K). From the calculation results, \( P \) value is 14380 μmK.
Figure 1. True color map (composite band of 432) of Lumut Balai geothermal area (A) and false color map (composite band of 567) of Lumut Balai geothermal area (B).

Digitizing the RBI map becomes a raster map to obtain Digital Elevation Model (DEM) data. DEM data does not need geometric and radiometric corrections. Then the DEM data processed to determine the slope through ArcGIS and the classification process is created, so that the slope map and land height map can be analyzed. The Hillshade effect applied to provide a better view. The slope of the land used in determining the potential and location of the power plant.
Figure 2. Composite band of 4/2, 6/7, and 5 image map to identification hydrothermal mineral in Lumut Balai geothermal area. The classification is based on previous research that is density slicing [7].

3. Result and Discussion
In composite image of true color (Figure 1), band 4 (0.78 – 0.90 μm) is placed on red channel, band 3 (0.63 – 0.69 μm) on green and band 2 (0.53 – 0.61 μm) on blue channel. The true color displays the appearance of satellite imagery that matches the actual color.

In false color image (Figure 1), band 5 (0.851 - 0.879 μm) on red channel, band 6 (1.566 – 1.651 μm) on green, and band 7 (2.107 – 2.294 μm) on blue channel. The false color gives an appearance the color of the object that is not actually real. The combination of the three bands is able to provide information about geological conditions that are better than true color composite images [7]. On the false color map, the presence of vegetation marked with a brownish-red color. Substantial vegetations found mostly in the slope or proximal region of the southwest part of the mountain. Whereas in the terrain or the bottom of the mountains, a blue-green area indicates the presence of open land and human activities.

Channel 4 (0.636 - 0.673 μm), channel 2 (0.452 - 0.512 μm), channel 5 (0.851 - 0.879 μm), channel 6 (1.556 - 1.651 μm), channel 7 (2.107 - 2.294 μm), and channel 10 (10.60 - 11.19 μm) used in determining the distribution of hydrothermal alteration minerals [8]. In a combination of channels 4/2, 6/7, and 5, the presence of hydrothermal alteration minerals shown as yellow, the drainage and settlement systems shown as red, and vegetation marked as turquoise to green [7]. The hydrothermal alteration which has the color of yellow-orange shown on the map is distributed in various places, especially in the north-eastern part of the Mt. Balai (Figure 2).
Figure 3. Map of vegetation index distribution in Lumut Balai area. The map shows the Lumut Balai area mostly covered by the vegetation mainly in the southern part of the map.

The range of NDVI values is from -1 to 1. The results of data processing show the minimum NDVI value is -0.85 and the maximum NDVI value is 0.88. On the vegetation index map (Figure 3), the areas that are greener have higher NDVI values, while the regions that are whiter are regions that have lower NDVI values. The phenomenon of absorption of red light by chlorophyll and reflection of near-infrared light (NIR) by mesophyll tissue found on leaves will make the different brightness value received by satellite sensors in both bands [4]. From the map, greener areas or higher NDVI values can indicate the presence of the vegetation. It occurs because the surface of vegetation reflects more radiation in the infrared wavelength compared to visible light. Whereas low NDVI value from the surface of clouds and water more reflects the visible wave energy than near infrared. However, the NDVI cannot be used as the only reference method to distinguish vegetation and non-vegetation objects. There is no clear and consistent threshold for NDVI values because it always changes following the season [4].
Commonly, areas that show good vegetation occur on the slope or area with high elevation. Moreover, the vegetation index map has an independent correlation with the value of surface temperature. The area with good vegetation on the map has a low surface temperature value, whereas the poor vegetation area has a high surface temperature value (Figure 4).

The Land Surface Temperature (LST) map shows the maximum surface temperature value is 40.3°C and symbolized as dark red, while the minimum surface temperature value is 7.6°C and symbolized as dark blue (Figure 5). There is an area that has a high LST value between the small LST value in the southwest which is flanked by two high elevations on the Lumut Balai and considered an anomaly. Besides that, there is a high LST value in some areas of the northern part of Mt. Balai which
is also inversely to the good vegetation index showing an anomaly. This anomaly can occur as a temperature effect that exists in geothermal manifestations and used as an initial review of determining geothermal potential.

The low LST value in the southwest of Lumut Balai can be affected by higher elevation while the higher LST values from the open land. In the northeast, high LST value more caused by open land and lower elevation. For an open land, the surface temperature is the temperature of the outermost layer of the land surface while for vegetation can be interpreted as the surface temperature of the plant canopy and on the water object is the temperature of the surface of the water. Likewise, the forest at the mountain has a minimum surface temperature. The high vegetation index value causes the recorded surface temperature to be low value.

![Map of Elevation Lumut Balai, South Sumatra](image)

**Figure 6.** Topography map of Lumut Balai geothermal area.

The elevation map of the study area has a range value from -69 to 3000 m (Figure 6). Near to the northeast, the altitude decreases. The geothermal anomaly occurs in the elevation of orange and yellow color that show the height is 3000 to 500 m. It has a great range that can occur in the hilly or steep area.

The slope map divided into 7 classes (Table 1), which refers to the relation of the slope class with the properties of the process and the suggested land conditions.

Areas that have high green colors show a sloping area while the purple area shows steep areas (Figure 7). On the map, steep slopes found on mountain slopes and valleys. For recommendations, the appropriate area for the power plant construction location is in the west, east, and northeast of the Mt. Lumut and Mt. Balai due to the slope that is not too steep, which ranges between 0 - 7% and characterized by dark green to light green areas.
Table 1. Slope classification and the description at each class to determine proper construction site [9].

| Slope classes | Description |
|---------------|-------------|
| 0° - 2° (0 – 2%) | Flat to almost flat, no meaningful denudation process |
| 2° - 4° (2 – 7%) | Gentle, low-speed ground motion, sheet erosion and soil erosion (sheet & fill erosion), erosion swamps |
| 4° - 8° (7 – 15%) | More gentle, the same as above, but with higher magnitude |
| 8° - 16° (15 – 30%) | Slightly steep, a lot of ground movement and erosion, especially landslides that are flat |

Figure 7. Slope map of Lumut Balai geothermal area based on Van Zuidam classification [9]. The site location recommendation that marked by cream color for power plant in Lumut Balai geothermal area.

The location of the sites is picked because of its closes to the source of geothermal energy. Based on the geological structure, the location is also not close to the fault shown on the map. Another parameter to determine areas that suitable for power plant locations based on land cover parameters, road access, and location of hot springs.

4. Conclusion
The geothermal exploration study of this area gives the information that there is an area that has a high value of land surface temperature between a low value in the southwest which is flanked by two
high elevations on the Mt. Lumut and Mt. Balai also in the southwest part of Mt. Lumut. This anomaly can occur as a temperature effect that exists in geothermal manifestations and used as an initial review of determining geothermal potential. Besides, the vegetation index map has an independent correlation with the surface temperature value. This can affect the surface temperature value, especially when geothermal is in hilly areas and has a good vegetation index. For recommendations on power plant locations, the appropriate area is found in the west, northeast, and east part of the Lumut Balai area due to the slope which is not too steep (between 0 - 7%) and it is characterized by dark green to light green areas.

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