Preliminary determination of geothermal working area based on Thermal Infrared and Synthetic Aperture Radar (SAR) remote sensing

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Abstract. Remote sensing is one of the methods for geothermal exploration. This method can be used to map the geological structures, manifestations, and predict the geothermal potential area. The results from remote sensing were used as guidance for the next step exploration. Analysis of target in remote sensing is an efficient method to delineate geothermal surface manifestation without direct contact to the object. The study took a place in District Merangin, Jambi Province, Indonesia. The area was selected due to existing of Merangin volcanic complex composed by Mounts Sumbing and Hulunilo with surface geothermal manifestations presented by hot springs and hot pools. The location of surface manifestations could be related with local and regional structures of Great Sumatra Fault. The methods used in this study were included identification of volcanic products, lineament extraction, and lineament density quantification. The objective of this study is to delineate the potential zones for sitting the geothermal working site based on Thermal Infrared and Synthetic Aperture Radar (SAR) sensors. The lineament-related to geological structures, was aimed for high lineament density, is using ALOS - PALSAR (Advanced Land Observing Satellite - The Phased Array type L-band Synthetic Aperture Radar) level 1.1. The Normalized Difference Vegetation Index (NDVI) analysis was used to predict the vegetation condition using Landsat 8 OLI-TIRS (The Operational Land Imager – Thermal Infrared Sensor). The brightness temperature was extracted from TIR band to estimate the surface temperature. Geothermal working area identified based on index overlay method from extracted parameter of remote sensing data was located at the western part of study area (Graho Nyabu area). This location was identified because of the existence of high surface temperature about 30°C, high lineament density about 4 - 4.5 km/km² and low NDVI values less than 0.3.

1. Introduction
Remote sensing is a common exploration technique for preliminary survey and aiding the complicated methods such as geology and geophysical surveys. Remote Sensing is the science and art of obtaining information about an object, area, and phenomenon through the analysis of data acquired by a device that is not contact with the object, area, and phenomenon under investigation [1]. In geothermal studies,
this method is not only used for exploration, but also in exploitation to monitor geothermal working area [2][3]. Remote sensing was used satellite imageries including optic and Synthetic Aperture Radar (SAR), to obtain reflectivity, emissivity, and scattering information from the target at ground surface. The results may be used as a basis for geological, geophysical and geochemical surveys [4].

This method is used to interpret surface condition based on color, texture, and structure from corrected imageries. The color difference from image can be interpreted as different physical properties of object or material at the ground surface [5]. Texture in the image might show the geomorphic stage of volcano, for example the smooth surface is relatively young stage due to less erosion process regardless rock type. Linear, circular, and radial structures of the ground surface could be identified based on Geomorphologic and Structural Features (GSF) in the imageries [6]. Based on GSF, major structures could be identified by lineament distribution and the high permeability could be interpreted by lineament density analysis [7][8]. In this study, the remote sensing data were used to detect the volcanic products, vegetation cover, and surface temperature.

Merangin area, in Jambi, was selected as study area because of the existence of surface manifestations with the remaining geomorphic of the eruption centers (figure 1). Therefore, the area is expected to have a geothermal system beneath the ground surface. However, there is not any exploration activity yet. The government has already made an auction for beginning exploration at the end of 2016 [9]. Thus, this study may hopefully usable for the exploration activity.

![Location Map of Study Area, Merangin, Jambi, Indonesia](image)

**Figure 1.** Location of study area showed by blue rectangle of the DEM SRTM 1 arcs and the subset image is Sumatra Island

The study area was composed by Hulu Simpang Formation, as the oldest formation, Granodiolit Langkup, Volcanic Rhoyo-Andesit Unit and Volcanic Breccia-Tuff Unit as the youngest formation. Quaternary Volcanic Lithology (Volcanic Breccia-Tuff Unit) formed the Mount Tua, Sumbing, Hulunilo
and Masurai (figure 2). The major structure near the study area is the Great Sumatra Fault from Northwest – Southeast that control the surrounding minor faults [10].

![Image](image_url)

**Figure 2.** Regional geological map of study area from [11] shows volcanic lithology distribution and great Sumatra fault from northwest to southwest.

2. **Image Processing**

2.1. **Optical Image**

Optical image used for this study is Landsat 8 OLI-TIRS containing eleven bands, from visible to thermal infrared region. The acquisition date on July 23rd, 2014. Eruption center, volcano base, geological structure on the surface, and vegetation cover were identified from Landsat 8 image.

The image processing was performed using ENVI 5.2 including radiometric calibration, atmospheric, and geometric corrections (figure 3). Radiometric calibration was used to convert digital number to radiance so that the data can be processed for atmospheric correction. The Fast Line of sight
Atmospheric Analysis of Spectral Hypercubes (FLAASH) embedded in ENVI was used for atmospheric correction. The reflectance produced after atmospheric correction is crucial to reduce the water vapor, oxygen, carbon dioxide, methane, ozone, molecule distribution, and aerosol in atmosphere. Following the atmospheric correction, geometric correction was applied to correct the geometric distortion. We used a Digital Elevation Model (DEM) from Shuttle Radar Topography mission (SRTM) data for georeferencing, registration, and rectification.

After corrections were applied, the color composite of RGB were used as basis of visual interpretation. RGB for band 4, 3, 2 showed the natural surface color, while RGB 5, 6, 7 showed false color. Both composites were used for volcanic products and lineament analyses. The Normalized Difference Vegetation Index (NDVI) was also used to identify the vegetation covers for estimating the leaf condition related to geothermal system beneath the surface [12]. The NDVI was calculated by incorporating the division of near infrared (NIR) and visible red bands. The NDVI indicated the distribution of rare and dense vegetation cover that the one might serve as an indicator of geothermal surface manifestation [12]. Visual observation based on natural color image is needed to confirm that low NDVI probably originated from surface manifestation, rather than clouds and infrastructures.

Landsat 8 OLI-TIRS provided thermal infrared bands for estimating brightness surface temperature in a specific location. Band 10 and 11 from Landsat 8 OLI-TIRS were used as input for calculating brightness surface temperature (figure 3). Radiometric calibration to generate radiance value from image digital number is presented by [13]:

\[ L_\lambda = \left( \frac{L_{\lambda_{\text{max}}} - L_{\lambda_{\text{min}}}}{Q_{\text{calmax}} - Q_{\text{calmin}}} \right) (DN - Q_{\text{calmin}}) + L_{\lambda_{\text{min}}} \]  

(1)

Where \( L_\lambda \) is sensor’s top atmosphere radiiances, \( DN \) is digital number, \( L_{\lambda_{\text{max}}} \) and \( L_{\lambda_{\text{min}}} \) are TOA Radiance scaled to \( Q_{\text{calmax}} \) and \( Q_{\text{calmin}} \), and \( \lambda \) is band wavelength.

The brightness temperature was calculated using following expression [14]:

\[ T = \frac{K_2}{\ln \left( \frac{L_\lambda}{L_{\lambda_{\text{min}}} + 1} \right)} \]  

(2)

\( T \) is sensor brightness temperature (K), \( K_2 \) and \( K_1 \) are calibration constant, depends on sensor and \( L_\lambda \) is spectral radiance. Brightness temperature can represent the surface temperature [14].

2.2. Synthetic Aperture Radar (SAR) Image

Synthetic Aperture Radar satellite is an active satellite that produce its own electromagnetic wave to earth surface, and obtain the backscattering wave from earth surface. The backscattering depends on roughness and dielectric property of the ground surface, thus the data are effective to produce a great quality image for geomorphologic and structural features identification [6]. SAR image has two acquisition methods, ascending, the acquisition from south to north, and descending in vice versa. SAR image used for this study is from ALOS PALSAR satellite level 1.1 data in ascending orbit. The acquisition time is November 9th, 2010.

We used SNAP 4.0 for SAR image processing. The processing contains radiometric calibration, multi-looking, polarimetric matrix generation, polarimetric speckle filtering, and geometric correction (figure 3). Radiometric calibration was used to convert the digital number to backscattering. Multi-looking process to increase the image focus without decreasing the resolution significantly.

In the SNAP SAR processing, the digital number must be in covariance and coherence matrices because it preserves the vector of the electromagnetic radiations and therefore, is preferred for complete analysis of the backscatter [15]. Therefore, the backscattering data were converted to covariance and coherence using polarimetric matrix generation [15]. The HH and HV polarisation band from ALOS PALSAR 1.1 were converted to C11, C12_real, C12_imag, and C22 using matrix generation C2. Matrix generation C2 consists of 2×2 matrix dimension with C11, C12, C12_image, and C22 are the scalar vector in the matrix [16]. Speckle filtering was applied to reduce the speckle noise in image using Refined Lee with window size 7×7 pixels.
After all calibration and polarimetric processing, the image needs a geometric correction. There were two geometric corrections applied: ALOS de-skewing and terrain correction. The ALOS de-skewing was used to convert inverse geometric to Doppler geometric. Whereas the terrain correction was used to evaluate the distortion from SAR geometry into map geometry using a Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM). The terrain correction is very important to reduce the foreshortening, layover, and shadow effect in the SAR image.

The local structures presented by lineament were extracted visually from corrected SAR images. Then, lineament density was calculated from the total of lineament in a specific area with a certain grid [8]. In this study, we used 100 × 100 m grid size, in accordance with the map scale, to represent the density of lineament in the study area more detail than 1×1 km grid size. The area with high density of lineament was interpreted as intensive structural zone.

**Figure 3.** Flowchart of data processing showed how to generate geothermal working area using optical and SAR image.
2.3. Delineating Geothermal Working Area

Geothermal working area was delineated visually based on index overlay method [17]. Index overlay method used three parameters which were processed, indexed and calculated for each detected target parameter including volcanic products, brightness surface temperature, and lineament density. Prospected geothermal area should have at least the heat source potential with high permeability reservoir. Since the most of geothermal heat source in Indonesia are volcanoes [18], the heat source possible location could be estimated at surface by delineating the volcanic formation including crater rim and volcanic products using shortwave infrared band [5]. The possible high surface permeability was estimated using lineament density (LD) from SAR image. We interpreted that high LD are associated with dense geological structures such as faults, fractures, and damage zones [8]. The existences of geothermal surface manifestation and high surface temperature indicated that there is path of hydrothermal fluid from the sub-surface to the ground [12][19]. Geothermal surface manifestation can be indicated by rare vegetation that is not caused by human activities [12]. NDVI analysis can be used to delineate the geothermal surface manifestation [12]. To analyse NDVI, true color composite image was needed to compare the rare vegetation and good vegetation index distribution. Brightness surface temperature was calculated using thermal infrared band from Landsat 8 [13, 14]. Using equation (1) and (2) surface brightness temperature can be generated. Combined heat source location, good permeability zone, and high surface brightness temperature can be used to delineate the geothermal working area. Detailed working flows was depicted by figure 3.

3. Results and Discussions

3.1. Volcanic products detection

Following Indonesia stratigraphic code [20], the volcanostratigraphic of study area are consisted of five hummocks which are divided into two crowns. Hummocks were formed by some rocks or deposits from one or more eruptions which form a volcano, and crowns are volcano stratigraphic unit which consists of eruption rocks or deposits from two or more hummocks. The first is Masurai Crown which have three hummocks, in order from the oldest to the youngest are Masurai Hummock, Kumbang Hummock and Mabuk Hummock. Masurai Hummock have a rougher texture than Kumbang Hummock, whereas Mabuk Hummock have no rough texture from erosion.

The second is Sumbing Crown. Sumbing Crown located in the west of study area. This crown contains Sumbing Hummock and Hulunilo Hummock. According to their conical shape and texture, these hummocks is quartenary and Hulunilo Hummock is relatively older than Sumbing Hummock. The maturity of hummocks were predicted by the image which show Hulunilo Hummock already erode more intensive than Sumbing Hummock. Sumbing Crown was selected as a potential geothermal working area because it is younger than Masurai Crown interpretatively. According to geological map from [11], both crowns was formed by Quaternary volcanic breccia with tuff matrix. Figure 4 shows volcano geology map with Sumbing Crown was delineate with yellow boundary and Masurai Crown with blue boundary.

3.2. Geothermal Surface Manifestation

NDVI analysis shows that there are low vegetation covers with index less than 0.3 (figure 5). The NDVI values were divided into five classes: red for very rare vegetation, yellow for poor vegetation, light blue for medium vegetation, dark blue for dense vegetation, and green for very good vegetation. NDVI using minimal and maximum value to get the comparison value for rare and dense vegetation, therefore the NDVI value is an index value, not an absolute vegetation covers.
Figure 4. Interpreted volcano geology map of study area using color composite RGB 5, 6, 7 for Landsat-8.
The rare vegetation are located in Masurai and Sumbing Crater and hot springs in Graho Nyabu. The NDVI value is lower than surrounding area about 0.3. Visual analysis using natural color Landsat-8 image shows that this area is not a manmade. It may imply that rare vegetation is probably caused by the effect from the ground such as hydrothermal fluids. This area is a potential for groundtruthing in the next steps.

Figure 5. NDVI Map (up) and natural color image (down). Low vegetation index marked with red squares.
3.3. Brightness Temperature

Brightness surface temperature shows that there are several areas with temperature above 30 °C (figure 6). Comparing to NDVI map, we classified the target area into two area: with and without human activities. According to NDVI and brightness temperature maps, rare vegetation in the southeastern part of study area, rare vegetation are more likely to be originated from housing and manmade (red square in figure 6).

Following the NDVI and brightness temperature analyses, the target area is predicted at the eastern part of study area which has high density of vegetation (green square in figure 6). The surface temperature at the target area is about 30 °C.

We interpreted that that the emitted heat comes from the existences of geothermal surface manifestation. This interpretation was confirmed by the existence of a hot spring presented by white dotted arrow in figure 6.

Dense vegetation with lower brightness temperature about 28 °C were detected near the central eruption (black square at figure 6). It can be indicated that the volcanoes are not active anymore but still have heat source of geothermal system beneath the surface [1]. Nevertheless, this interpretation still needs direct groundcheck in the area.

Figure 6. Brightness temperature map in °C using Band 10 for Landsat-8 data showed the low and high anomaly zones presented by black and red rectangles.
3.4. Lineament Density

Lineament density was analysed using SAR image because it shows the structure clearer than optical image [21]. The small and local structure could be detected extensively.

Geothermal prospect area is associated with high lineament density. Geothermal surface manifestation presented by hot springs were detected in the area with high lineament density, about 4.5 km/km², on Graho Nyabu (figure 8). The lower lineament density is about 2 km/km² and no surface manifestation found in the east of Graho Nyabu.

Figure 7. Processed SAR image RGB C11, C22, C11/C22 (up) and lineament extraction from the left image (down).
4. Suggested Working Area

Index overlay method used to delineated geothermal working area using processed, indexed and calculated parameters include volcanic products, geothermal surface manifestation, surface temperature, and lineament density. Volcanic product distribution can be delineated using volcano geology analysis with target area at Sumbing Crown (figure 4). Surface temperature can be estimated using Thermal Infrared Sensor and the result showed that the area with high brightness temperature is located in the west study area (figure 6). The area with high lineament density was located in Graho Nyabu, west of study area, with Great Sumatra Fault serve as a permeable structure (figure 8). The existence of hot springs indicated that there is geothermal surface manifestations. Other manifestation which predicted using NDVI and brightness temperature analyses was detected in south area of Graho Nyabu, but still need to be evaluated with groundcheck in the next steps (figure 5). Local structure that surrounding Graho Nyabu can be the system boundary, because area outside boundary structure have a low lineament density. Geothermal working area was predicted based on overlay of all these maps as depicted by figure 9.

Figure 8. Lineament density image with target area presented by grey rectangle.
Figure 9. Index overlay map of the three parameters: brightness surface temperature anomaly in green rectangle, volcanic product in blue rectangle, and lineament density anomaly in pink rectangle (left) were used to estimate the geothermal working area (right).
5. Conclusions
Remote sensing is an effective method in an early stage of geothermal preliminary exploration. From this method, the brightness temperature, volcanic product, and lineament density could be extracted to interpret the possibility of geothermal working area based on index overlay method. The identified area was located at the west of study area (Graho Nyabu area) because of the existence of high brightness temperature about 30°C, high lineament density about 4 - 4.5 km/km², and low NDVI value less than 0.3. Addition parameters are necessary to be included to obtain a comprehensive working area such as local government boundaries as well as forest conservation. Ground-truthing are aimed to the next step for validating the result so that delineated working potential could be used for guiding the geological, geophysical, and geochemical surveys.

References
[1] Lillesand T M Kiefer R W and Chipman J W 2015 Remote Sensing and Image Interpretation, 7th ed (New Jersey: John Wiley & Sons)
[2] Saepuloh A 2013 Potential Use of Synthetic Aperture Radar (SAR) Data for Geothermal Exploration (Yogyakarta: Proceedings of International Conference on Geological Engineering)
[3] Bromley C Ashraf S Seward A and Reeves R 2015 Monitoring and Quantifying Heat Loss from Significant Geothermal Areas Via Remote Sensing (Taupo: Proceedings of 37th New Zealand Geothermal Workshop)
[4] Sumintadireja P and Saepuloh A 2013 Significant Role of Remote Sensing Technology in Geology Exploration (Denpasar: Proceeding of the 34th Asian Conference on Remote Sensing 2013)
[5] Saepuloh A Koike K Sumintadireja P and Nugrah A D 2008 Digital Geological Mapping using ASTER Level-1B in Relation with Heat Source of Geothermal System in an Active Volcano (Jakarta: ISTECS Journal)
[6] Saepuloh A Koike K Urai M and Sri S J T 2015 Identifying Surface Materials on an Active Volcano by Deriving Dielectric Permittivity from Polarimetric SAR Data IEEE Geoscience and Remote Sensing Letters (GRSL) (New Jersey: IEEE) 12 1620-1624.
[7] Akbari D and Saepuloh A 2016 Identification of Surface Manifestation at Geothermal Field Using SAR Dual Orbit Data IOP Conf. Series: Earth and Environmental Science
[8] Iswahyudi S Saepuloh A and Widagdo A 2014 Delineating Outflow Zones Using Linear Features Density (LFD) Derived from Landsat Imagery at Paguyangan, Brebes, Central Java (Bandung: Proceedings of 3rd International ITB Geothermal Workshop 2014)
[9] Investment Catalogue 2017 2017 Ministry of Energy and Mineral Resources Republic of Indonesia
[10] Barber A J Crow M J and Milsom J S 2005 Sumatra: Geology, Resources and Tectonic Evolution Geological Society (London: Memoirs)
[11] Kusnama R Pardede S, Mangga A, Sidarto 1992 Geological Map of the Sungaipenuh and Ketaun Quadrangle, Sumatra (Indonesia: Geological Research and Development Centre)
[12] Suryantini Wibowo H Rahman K R Woldai T 2013 Application of Normalized Different Vegetation Index (NDVI) Method to Identify Thermal Anomaly Area from Remote Sensing (Jakarta: Proceeding 13th Indonesia International Geothermal Convention & Exhibition 2013)
[13] Barsi J A Barker J L and Schott J R 2003 An Atmospheric Correction Parameter Calculator for a Single Thermal Band Earth-Sensing Instrument (New Jersey: IEEE)
[14] Chander G Markam B L and Helder D L 2009 Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI Sensors Journal Remote Sensing of Environment. (Amsterdam: North-Holland/American Elsevier) 113 893 – 903
[15] Verma V 2012 Polarimetric Decomposition Based on General of Scattering from Urban Areas and Multiple Component Scattering Model Thesis of Faculty of Geo-Information Science and Earth Observation of The University of Twente (Twente)
[16] ESA SNAP 4.0 Module 2016 Scientific Exploitation of Operational Missions
[17] Suminar W Saepuloh A and Meilano I 2016 Identifying Hazard Parameter to Develop Quantitative and Dynamic Hazard Map of an Active Volcano in Indonesia AIP Conference Proceeding (New York: AIP Publishing)

[18] Hochstein M P and Sudarman S 2015 Indonesian Volcanic Geothermal System Proceedings of World Geothermal Congress

[19] Darajat F I Maris E E P Akib A A Guswinanda H and Saepuloh A 2016 Analyses of Landsat 8 Imagery for Preliminary Assessment to Determine Geothermal Potential Area under Torrid Zones (Strasbourg: European Geothermal Congress 2016)

[20] Sandi Stratigrafi Indonesia Ed 1996 2010 Ikatan Ahli Geologi Indonesia

[21] Joshi N Baumann M, Ehammer A Fensholt R Grogan K Hostert P Jepsen M R Kuenmerle T Meyfroidt P Mitchard E T A Reiche J Ryan C M and Waske B 2016 A Review of the Application of Optical and Radar Remote Sensing Data Fusion to Land Use Mapping and Monitoring Remote Sens