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Assessing of Land Surface Temperature at the Seulawah Agam Volcano Area using the Landsat Series Imagery

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Abstract. Seulawah Agam, a stratovolcano located in the Aceh province, Indonesia, has not erupted for a long decade after the last eruption in 1839. Thermal infrared remote sensing has been used to determine the land surface temperature (LST) of the volcano area. However, the application of remotely sensed thermal imagery in identifying the LST of the Seulawah Agam volcano, as a precursor of geothermal energy and eruption hazard, has not been completely monitored. The volcano locates relatively close to residential areas, which is a challenging approach to apply thermal bands in determining geothermal identities. In this research, we assess the LST and vegetation index for the detection of the thermal activity of the mountain. These characteristics were retrieved from Landsat 7 ETM+ and Landsat 8 TIRS/OLI imageries, acquired on 23 April 2004 and 16 March 2015 over the Seulawah Agam area, respectively. The normalized difference vegetation index (NDVI) threshold method for emissivity retrieval and split-window algorithm for land surface temperature (LST) were utilized. The results show that the vegetation index changes moderately over the geothermal area, especially at the residential area and western side of the volcano which is in line with a fault structure of the Seulimeum segment. We calculated the LST from the thermal bands of Landsat images 2004 and 2015 with approximate results are 28 – 35 °C. The spatial distribution of surface temperatures at the mountain derived from the classified image 2015 varies considerably compared with the classified image 2004. The surface temperature and vegetation index changes indicate a thermal activity at the Seulawah Agam volcano. It can be concluded that the Landsat 7 ETM+ and Landsat 8 TIRS/OLI imageries are potentially used to study the thermal status of the Seulawah Agam geothermal area.

1. Introduction

Seulawah Agam, an active volcano in the Aceh province, Indonesia, has the potential for developing a geothermal power plant. The stratovolcano exhibits an estimation of geothermal energy reserve at about 165 Mwe, with 7 manifestations which are located on both the north and south sides of the mountain [1]. Several studies and approaches have been explored to identify and estimate geothermal resources of the Seulawah Agam volcano, such as magnetotelluric [2], transient electromagnetic [3], and geochemistry methods [1]. However, the geothermal characteristics of the volcano have not been comprehensively assessed using remote sensing approaches. The remotely sensed techniques have been applied for determining and estimating surface temperature [4], hydrothermal mineral deposits [5], and vegetation indexes over various volcano areas in the world [4,6,7]. Those essential properties can be
extracted from the spectral bands or spectral signatures of spectroscopic laboratory data [7,8] and satellite imagery in the wavelength range of visible and near infrared (VNIR), shortwave infrared (SWIR), and thermal infrared (TIR). The thermal bands have shown their capability to examine and observe the geothermal exposure, particularly land surface temperature (LST) [4,9], which is emitted by the fluids and hot rock around the heat-source of the reservoir [10].

The ability of thermal infrared remote sensing to continuously record the spectral and spatial data of the active volcano contributes to the geothermal resource assessment [5], the evaluation of geothermal exploration impact on the environment, and the mitigation of eruption hazards [4,11] of the mountain in the future [9,12]. Furthermore, remote sensing methods have also been deployed for mapping and identifying surface mineralogy [8,13], geological hazards [14,15], and lithological and geological prospecting areas [16]. In this research, we explore and monitor the LST and normalized difference vegetation index (NDVI) of the Seulawah Agam volcano using Landsat series imagery. Landsat 7 ETM+ and Landsat 8 OLI/TIRS images, acquired on 23 April 2004 and 16 March 2015 respectively, were used to retrieve these characteristics of the geothermal area. The study of geothermal identities using remote sensing techniques could help in understanding the thermal activity and predicting the renewable energy reserves of the volcanic mountain.

2. Study Area and Geological Setting

The Seulawah Agam volcano was formed by the tectonic activities on the subduction zone between the Indian-Australian and Eurasian plates [17]. The mountain is located in the Seulimeum subdistrict of the Aceh Besar region, the Aceh province, Indonesia. The geologic map (Figure 1.a) shows that the rock formation of the volcano is dominated by Lam Teuba volcanic rocks, which consist of andesitic to dacitic volcanic, pumiceous breccias, tuffs, agglomerates, and ash-flows of the Pleistocene period, as well as mud-flows deposited on Lam Teuba volcanic parent rocks are within the Holocene geologic time [18]. The Seulawah Agam volcano has two prominent manifestations, namely Ceumpaga and Heutz craters situated on the south and north sides of the mountain respectively. The surrounding volcano areas also have several hot-springs, such as Ie Suum at Krueng Raya subdistrict and Ie Jue at Meurah village, Lam Teuba subdistrict, Aceh Besar.

Moreover, the tectonic activities of the Indian-Australian plate had formed the Sumatra Fault, elongated from Lampung to the Andaman sea. The Fault split into two segments, Aceh dan Seulimeum segments, on the northern side of the Aceh province [19–21]. Those segments have contributed and controlled the existing of the Seulawah Agam volcano [3,17]. Figure 1.a exhibits the Sumatra Fault within the volcanic area, which is pointed out by black lines in a northwestern-southeastern direction of the Aceh province. Geomorphologic map of the study site (Figure 1.b), derived from Landsat imagery by mean of the band composite technique (RGB: 5, 6, and 7 bands), demonstrates the physical feature characteristics corresponding with the lithological formation of the volcanic mountain. An alluvium deposit of fine-grained texture (light blue) can be observed on the northern side of the geothermal area (Figure 1.b). However, the geomorphologic data indicates the volcanic rocks of rough-grained texture with dark brown color on the volcano area (Figure 1.b).
3. Material and Methods

Landsat Series Data Collection Level-2, Landsat 7 ETM+ and Landsat 8 OLI/TIRS images recorded on 23 April 2004 and 16 March 2015, respectively, were used for this study. The data with corrected geometry were acquired from https://earthexplorer.usgs.gov. To calculate the LST of the Seulawah Agam geothermal area, a series of processes, such as radiometric correction, brightness temperature, and emissivity calculations [22], have been applied to the Landsat images. The radiometric correction employed on the images, to convert digital number (DN) values into spectral light, was computed using the following formula:

$$L_{\lambda} = M_{\lambda} Q_{\text{CAL}} + A_{\lambda}$$

$L_{\lambda}$ is the spectral light (W/m²srμm), $M_{\lambda}$ is the radiance multiplicative scaling factor for the band, the $A_{\lambda}$ is the radiance additive scaling factor for the band, and $Q_{\text{CAL}}$ is the pixel value in DN. However, thermal bands, band 6 for the Landsat 7 ETM+ and band 10 for the Landsat 8 OLI/TIRS images, were converted into brightness temperature. The brightness temperature was calculated using the Plank radiation model:

$$T = \frac{K_2}{\ln \left( \frac{K_2}{L_{\lambda}} + 1 \right)}$$

$T$ is the brightness temperature (K), $L_{\lambda}$ is top of the atmosphere (TOA) spectral radiance (W/m²srμm), and $K_1 = 774.8853$ and $K_2 = 1321.0789$ are the conversion constants of the thermal bands. The brightness temperature is the temperature recorded by a satellite sensor on the assumption that the surface emissivity value was disregarded. Therefore, it requires the normalized difference vegetation index (NDVI) data to retrieve the emissivity value from the Landsat images. The vegetation index function, which is a combination of two spectral bands: red and near infrared bands [23,24] is given by
\[ \text{NDVI} = \frac{R_{\text{NIR}} - R_{\text{RED}}}{R_{\text{NIR}} + R_{\text{RED}}} \]

Where \( R_{\text{NIR}} \) is NIR bands, band 4 and band 5, and \( R_{\text{RED}} \) is red bands, band 3 and band 4 obtained from Landsat 7 ETM+ and Landsat 8 OLI/TIRS images, respectively.

Land surface temperature (LST) of the volcanic geothermal area was computed using the following equation of single-channel algorithm [10]:

\[ T_S = T_{\text{sensor}}/1 + (\lambda \times T_{\text{sensor}} \rho) \ln \varepsilon \]

Where \( \lambda \) is the wavelength of the radiation (\( \lambda = 11.5 \mu \text{m} \)), \( \rho = hxc/ j \) in mK, \( h \) is the Plank constant \( (6.626 \times 10^{-34} \text{ Js}) \), \( c \) is the speed of light \( (2.998 \times 10^8 \text{ m/s}^2) \), and \( j \) is the Boltzmann constant \( (1.38 \times 10^{-23} \text{ J/K}) \), \( T_{\text{sensor}} \) is the brightness temperature and \( \varepsilon \) is emissivity retrieved from the NDVI data.

4. Results and Discussion

The NDVI classification results of the red and near infrared spectral bands combination of Landsat images on the Seulawah Agam volcano area are shown in Figure 2. The spectral vegetation index maps show variations and changes in the vegetated surface and cover of the geothermal area. The NDVI values of the classified images vary moderately from -0.1 to 0.8. The highest value indicates dense vegetation area, whereas the lowest value attributes to less-vegetated or un-vegetated land cover or outcrop areas. In general, the highest vegetation index between 0.7 and 0.8 (green pixels; Figure 2) is located in the mountain slopes. The tropical forest areas around the volcano slopes are not affected by human activities and are away from residential areas. The lowest vegetation index is predominantly found in less-vegetated or un-vegetated areas, which are situated on the mountain side of the geothermal area. The 2004 and 2015 NDVI classified images (Figure 2) exhibit several less-vegetated or un-vegetated surfaces at the northwestern part of the mountain, such as residential area, Ie Busuk manifestation, and Ie Jue hot-spring. Those land cover types can also be observed in the southwestern part of the volcanic mountain (Figure 2).

Furthermore, Figure 2 exhibits less-vegetated or un-vegetated areas around Alue PU manifestation, which are attributed to alluvial fan areas of the mountainside. These alluvial areas can trigger off a landslide due to the gradual disintegration of soil retention by increasing the infiltration of rainwater into the soil and gravitational force. It is a high risk to the residential area located on the bottom of the alluvial zone. The 2015 classified vegetation image illustrates a slightly different spatial distribution of less-vegetated or un-vegetated surfaces, as compared to the 2004 classified image. The resulting proportion of less-vegetated or un-vegetated surfaces from the NDVI result of image 2015 increases slightly in residential and geothermal areas (Figure 2). The rising less-vegetated or un-vegetated surface around the hydrothermal reservoir area from the Heutz crater toward Alue Ie Masam [3] indicates a gradual increase in magmatic activity of the Seulawah Agam volcano. These NDVI data were used to compute the emissivity value of the geothermal area, as the main parameter for assessing the LST.
Figure 2. The NDVI maps of the Seulawah Agam geothermal area extracted from the 2004 and 2015 Landsat images. The highest value (green color) indicates vegetated surfaces and the lowest value (yellow and red colors) associates with less-vegetated or un-vegetated surfaces. The classified images illustrate nearly the same spatial distribution of vegetation patterns in the volcano area.

Figure 3 shows the LST classified images of the Seulawah Agam volcano area derived from the 2004 and 2015 Landsat images. The surface temperature values of the mountain vary between 28 °C and 35 °C. The lowest temperatures (28 – 30 °C) are generally on the mountainside at an altitude of 1810 mdpl, whereas the highest temperatures (34 – 35 °C) are found on the foot of the volcanic mountain (Figure 3). The LST data of the classified image 2015 illustrate a considerable variation in the overall spatial distribution of surface temperatures at the Seulawah geothermal area compared with the classified image 2004. It demonstrates a gradual increment in the surface temperatures of the volcanic mountain, which are probably associated with the increased thermal activity of the Seulawah Agam volcano. The LST values around the manifestation sites, such as Ie Busuk, Ie Jue, Alue Tungku, and Alue Ie Masam, that located in the northwestern and southwestern parts of the volcanic mountain (Figure 3), are approximately 32 – 35 °C. These surface temperatures are not only influenced by the thermal activity of the volcano, but also human activity in the residential and agricultural areas of the mountain foot. Each of the Earth's surface features has diagnostic characteristics in the emission of electromagnetic radiation, which depends on the surface feature temperature [4]. Hence, the changing of soil surface temperature can be attributed to understanding and predicting volcanic activity and geothermal energy resources of the Seulawah Agam mountain.
Figure 3. Land Surface Temperature (LST) maps of the Seulawah Agam geothermal area extracted from the 2004 Landsat 7 ETM+ and the 2015 Landsat 8 OLI/TIRS images.

The surface temperatures, around an expected hydrothermal reservoir of the Seulawah Agam geothermal area from Heutz crater to Alue Ie Masam [3], slightly increase over a decade (Figure 3). We can observe a substantial change in the spatial distribution of surface temperature around the top of the volcano, which elongates from NW to SE with a dimension of 3.5 km in the classified LST image 2004 and is relatively ellipse with a dimension of 2.8 km in the classified LST image 2015 (Figure 3). Those variations and changes in the surface temperatures of the Seulawah geothermal area indicate the existence of magmatic activity at the depth of the Earth.

5. Conclusion
The Landsat series imagery is investigated to determine the geothermal characteristics, such as normalized difference vegetation index (NDVI) and land surface temperature (LST), on the Seulawah Agam volcano area. The spatial distribution of vegetation patterns and surface temperature over the volcanic mountain has been changed for the last decade, which indicates an increase in thermal and human activities in the geothermal area. The NDVI and LST identities derived from Landsat 7 ETM+ and Landsat 8 TIRS/OLI images are helpful in assessing thermal activity and predicting the geothermal energy potential of the Seulawah Agam volcano.

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