Detection of ground thermal anomaly under dense vegetation based on ASTER TIR images

Citra Aulian Chalik¹, Asep Saepuloh², Suryantini²
¹Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung
²Faculty of Earth Sciences and Technology, Institut Teknologi Bandung
Jl. Ganesha No.10, Bandung, West Java, 40132, Indonesia.

Email: citrachalik15@gmail.com

Abstract. Ground thermal anomalies associated with geothermal surface manifestations such as hot springs, fumaroles, altered surfaces, and steaming grounds serve as crucial indicator for geothermal explorations. In order to highlight the ground thermal anomalies, this study was raised to use the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data to estimate surface temperature under condition of dense vegetation. This study was focused to exploit the ASTER Thermal Infrared Radiometer (TIR) under lab and field scale conditions. The ASTER TIR bands were used to extract the Land Surface Temperature (Ts) from radiances by excluding surface emissivity (εs). The ε is a surface parameter dependent to the surface materials. In this paper, we demonstrated the performance of the Normalized Emissivity Method (NEM) to calculate the Ts by estimating the ε under condition of dense vegetation. The Patuha and Wayang Windu Geothermal field in West Java (Indonesia) were selected as study site due to existence of surface manifestations under canopy vegetation and open area. According to the method, we identified that the ground thermal anomalies are located at surface manifestations. Due to the different spatial scales of satellite and surface measurements and the lack of homogeneous areas, which are representative for low resolution pixels and ground measurements, ground-validation is necessary. The consistency between ASTER data and location of geothermal manifestations indicated that thermal remote sensing data integrated with a spatial-based model, provides an effective means for identifying geothermal potential.

1. Introduction
Surface manifestations are the sign of geothermal system on the ground surface. The existence of geothermal resources can be demonstrated the presence of surface manifestations. High-resolution thermal infrared (TIR) remote data provide a unique opportunity to derive thermally emitted radiance information from the land surface [1], this paper investigates the Land Surface Temperature (Ts) associated with geothermal features in Patuha and Wayang Windu. Both gothermal fields are well suited for remote sensing experiment to detect geothermal features because the geothermal system occurs over large area and the Putih and Wayang crater relatively sparse vegetative cover as manifestation on open area, even though surface manifestations are under dense vegetation. However, cavity effect should be taken into account at the vegetation canopy level, to avoid an underestimation of emissivity, especially for intermediate vegetation conditions between bare soil and full vegetation cover [3].
Extracting Ts of ground target based on satellite thermal infrared is complicated due to several unknown parameters such as emissivity and noise from environment [4]. Thermal emissivity $\varepsilon_s$ useful to know because it is necessary as a control in atmospheric and energy-balance models [5], since it must be known along with brightness temperature to establish the heat content of the surface. Moreover, investigated field study under conditions of dense vegetation makes the problem worse due to the shallower layer penetration of the response at wavelengths of thermal infrared compared microwave energies [6].

This study we simulated the performance of the Normalized Emissivity Method (NEM) to calculate the Ts and $\varepsilon_s$ derived from ASTER TIR. The main target of this paper is to estimate the Ts under condition of dense vegetation based on NDVI (Normalized Different Vegetation Index) value derived from ASTER data. Finally, the main results of the comparison between anomaly thermal under dense vegetation confirmed by ground measurement, as well as conclusions of the study.

2. Data and Methodology

2.1. Data

The study area is located in Patuha and Wayang Windu geothermal fields (Figure 1). Patuha is situated on a high plateau (2400 m of Mt. Patuha) and Wayang Windu is located at the eastern Patuha. The elevation of the Mt. Wayang is 2120 m and Mt. Windu is 2160 m. The Patuha is known for its geothermal features such Rancawalini, Cimanggu, Putih crater, Cisaat, Cibuni, Tiis, Cibunggoak, and Cwidey. In addition, Geothermal features of Wayang Windu are Kertamanah, Pejaten, Sukaratu, Cipanas, Sukaratu and Cibolang.

The Advanced Space Thermal Emission and Reflection Radiometer (ASTER) data, on board the Terra satellite, has three bands in the VNIR (Visible and Near Infrared Radiometer), six bands in the SWIR (Shortwave Infrared Radiometer) and five band in the TIR (Thermal Infrared Radiometer) with 15, 30 and 90 m of spatial resolution, respectively [9]. The central wavelengths for the five ASTER TIR bands 10-14 are 8.30, 8.65, 9.05 10.60 and 11.30 µm. The ASTER TIR data acquisition times used in this study, which cover Patuha and Wayang Windu manifestation areas under ideal nighttime. The ASTER data of Patuha area is consisted of two pairs of ASTER L1T scenes acquired 20 June 2015 for day-time and 10 September 2015 for night-time. For Wayang Windu area, the data were acquired 20 June 2015 for day-time and 8 July 2015 for night-time. Day-time data were not available for the same dates as the night-time data. The Digital Elevation Model (DEM) SRTM (Shuttle Radar Topography Mission) Patuha area (Figure 2) and Wayang Windu area (Figure 3) overlay on Shaded map DEM SRTM 30 m.
Figure 1. Location Map of Study Area, Black Square shows Patuha Area, Blue Square shows Wayang Windu Area, and Red Square refers to Two Study areas which are located in West Java.
2.2. *Retrieval NDVI*

Normalized difference vegetation index (NDVI) for an ASTER imagery is calculated using bands 2 and 3. The visible red light in ASTER is located in band 2 with spectral range 0.63-0.69 µm, whereas
the near infra-red is within the range 0.78-0.86 \, \mu m in band 3. The equivalent NDVI formula using ASTER data is as shown in Equation 1 [8]:

\[
\text{NDVI}_{\text{ASTER}} = \frac{\text{band} \, 3 - \text{band} \, 2}{\text{band} \, 3 + \text{band} \, 2}
\]

2.3. Normalized Emissivity Method (NEM)
Separating emissivity and temperature from TIR data consists of estimating waveband emissivity for a given channel to next retrieve all the waveband emissivity and the radiometric temperature [3]. The NEM separates temperature form emissivity has been employed to calculate the temperature of each pixel. For calculating the Surface Temperature \((T_s)\) and Surface Emissivity \((\varepsilon_s)\), we retained the assumption \(\varepsilon_{\text{max}} = 0.98\) of each pixel from ASTER band, which we used equation 2 [2]. The max \(T_b\) from all bands \(b = (b_{10-14})\) is assigned as the \(T_s\) of the pixel using equation 3. \(T_b\) used to calculate the \(\varepsilon_s\) of each band using equation 4.

\[
\int_{10}^{14} T_b = \frac{C_2}{\lambda_b} \left( \ln \left( \frac{C_1 \varepsilon_{\text{max}}}{\pi R_b \lambda_b^4} + 1 \right) \right)^{-1}
\]

\[
T_s = \max (T_b)
\]

\[
\int_{10}^{14} \varepsilon_b = \frac{R'_b}{B_b(T_b)}
\]

Where: \(b = 5\) bands \((b_{10}, b_{11}, b_{12}, b_{13}, b_{14})\)
- \(T_b\) = temperature in each band
- \(C_1 = 3.74151 \times 10^{-16}\) W/m²
- \(C_2 = 0.0143879 \times 10^{-16}\) mK
- \(\lambda_b\) = wavelength in each band
- \(R_b\) = Radiance in each band \((\text{Wm}^{-2} \, \mu \text{m}^{-1})\)
- \(\varepsilon_s\) = emissivity in each band
- \(B_b\) = Blacbody radiance in each band

We used ENVI 5.4 program that separates the \(\varepsilon_s\) and \(T_s\) information in radiance data measured with thermal infrared sensors.

2.4. Ground Temperature (\(T_g\))
In situ ground temperature was carried out measurement within the test site. Ground measurements were concurrent with the ASTER overpasses to compare in situ and satellite-derived data under similar atmospheric conditions. There are 140 locations of ground measurements in Patuha area and 269 locations in Wayang Windu area.
3. Result and Discussion

3.1. Vegetation Cover Analysis

Radiometric and atmospherically corrected image were identified to identify surface characteristic in Patuha and Wayang Windu Geothermal Field, including vegetation cover, surface manifestation, and thermal anomaly zone. Results from NDVI calculation are illustrated in Figure 4 and 5. The output NDVI image has a value range of 0 to 1. In Figure 4 shows Patuha area, zones with NDVI value >0.5 are assigned a yellow to green color range and zones with NDVI value < 0.5 are assigned a yellow to red color range. The NDVI image analysis was done through comparison with true color composite of Landsat 8 in the same area. According to the Landsat 8 image, it can be seen that those area are open area or non-vegetation cover by human eyes. Green to yellow color is generally vegetated area, whereas yellow to red color is bare ground or non-vegetation area.

The NDVI anomaly map and the associated true color composite of Patuha area is shown in Figure 4. It is obvious that the Putih crater show red NDVI anomaly surrounded by green NDVI. In other areas around the surface manifestation are relatively dominated by cover vegetation and small yellow to reddish NDVI area, this indicates the area is a bare soil or water body.

Figure 4. True Color Composite (A) and NDVI map (B) of Patuha area. Black circle in NDVI map is water body of Putih crater and Blue circle in NDVI map is PT. Geo Dipa Geothermal Company.
The NDVI anomaly map and the true color composite of Wayang Windu area is shown in Figure 5. Most surface of Wayang Windu area is light red color with some rectangle man-made features. All of manifestations are located in the yellow to red color NDVI. In the NDVI map the red color NDVI anomaly mostly are associated with bare soil which in the North East (NE) and man-made features which in the South East (SE). In such condition like in Wayang Windu area, the analysis of NDVI becomes very limited.

3.2. Land Surface Temperature ($T_s$)

The Land Surface Temperature ($T_s$) is obtained from the separation of temperature and emissivity of ASTER TIR data. The ASTER TIR data used to obtained $T_s$ is night-time scan.

The $T_s$ map derived from ASTER TIR data of Patuha area shown in Figure 6. According to the Figure 6 yellow-green area in the northwest indicate dense vegetation, meanwhile in the northeast, though according to $T_s$ it shows high temperature area, it is not related to thermal anomaly. High value of $T_s$ due to thermal anomaly are located in Putih crater 24°C, Cisau 14°C, and Cibuni 14°C. These areas may be areas that could potentially have geothermal energy. We detect $T_s$ anomalies associated with other manifestations. One location of thermal anomaly is in the southeast named Ciwidey Crater 13°C, in the south there are Cibunggoak 11°C, and Tiis Crater 12°C. In the northwest also detected thermal anomaly which recognize as Rancawalini 12°C and Cimanggu 12°C.
3.3. Emissivity ($\varepsilon_s$)

NEM is used to minimize the variance of the emissivities. For graybodies, the re-estimation of emissivity max reduces its sensitivity to measurement error by a factor. This average surface emissivity was compared to those retrieved by NEM applied to ASTER data assuming an max emissivity 0.98, which is close to the measured emissivity spectra.

We obtained emissivity spectra from 8 locations which 4 locations in Wayang Windu area (1-4) and, and 4 locations in Patuha area (4-8) shown in Figure 7.

Emissivity depends on factors such as temperature, emission elevation angle, and radiation wavelength. The spectral emissivity shown in Figure 7. Higher value $\varepsilon_s (>0.96)$ in dense vegetation is normal if we assume more moisture content can cause higher $\varepsilon_s$, in the other hand the lower $\varepsilon_s$ value (<0.96) probably caused the condition in this area shown open area, steaming ground and other characteristic surface. So that in Putih crater shown the higher $\varepsilon_s$ value (0.98) and location in point 4 lower than Cibolang area about 0.002 difference. Relationship between $T_s$ and $\varepsilon_s$ is a determine approach. In this study, $\varepsilon_s$ factor is very influential on the temperature radiance, the higher emissivity the higher temperature radiance which is close to blackbody condition. The result according to graph on Figure 7, $\varepsilon_s$ curves always follow $T_s$ curves under all dense vegetation and rare vegetation condition. The high $T_s$ in Putih crater (24.9°C) and Cibolang manifestation (8.8°C) under dense vegetation or rare vegetation area indicate the temperature from warm pool crater and hot spring.
3.4. Comparison of ASTER $T_s$, $T_g$, and NDVI

We compared the areas which identified as thermally anomalous to the thermal areas obtained from ground measurements, also the hot springs and crater were plotted over the study area. On Figure 8 it can be outlined that the dense vegetation cover is one of the influential in controlling decreased $T_s$, based on NDVI value, the graph indicates that the area having lower $T_s$ were in more dense vegetation cover.

Figure 10 and 11 show $T_s$ anomaly associated with the presence of manifestations that comparison with $T_g$. The high anomalies from ground thermal measurement in Patuha area (Figure 9) are Barutunggul 25.7°C, Ciwidey 43.5°C, and Cibuni 42.5°C. In Wayang Windu area, there are three locations high ground thermal such as Burung crater 93°C, Wayang crater 69°C and Cibolang 92°C. However, the high anomaly from $T_s$ ASTER data showed there are significant temperature values with ground temperature on direct measurement in the field such as Putih crater which on $T_s$ ASTER show 24.9°C, but according direct ground thermal measurement show 19.1°C, Burung crater which on $T_s$
ASTER show 47.4 °C, but according direct ground thermal measurement show 94 °C, Cibolang and Wayang crater (Figure 10).

![Graph showing relationship between Ts and NDVI](image1)

**Figure 8.** The Relationship between T_s and NDVI, (A) it is in Patuha area, and (B) it is in Wayang Windu area.

Figure 11 shows graph comparison T_s, T_g, and NDVI in our study area. We retrieval from 10 locations of Patuha and there are 7 locations of Wayang Windu located in the manifestation area. Based on T_s ASTER data the temperature distribution in Patuha is higher than Wayang Windu, but based on T_g value Wayang Windu is higher than Patuha where three locations in Burung crater, Wayang crater, and Cibolang up to 93 °C, 69 °C, and 92 °C, respectively. The temperature distribution which the satellite thermal infrared sensor will detect only small amount of the remaining surface temperature, this is an effect on the density of vegetation cover. The vegetation reduced temperature about 30% in the day and 50% in the night based on presented experimental [7]. So that in our study area, T_s in Putih crater is over estimate than T_g which the Putih crater is non-dense vegetation or 0% vegetation cover. Difference from the others, the NDVI value is >0 when compared with Putih crater NDVI (-0.4).
Our approach does have some limitations, as indicated by some falsely identifiable topographic, resolution, and surface orientation effects. Another possible cause by dense vegetation, thereby reducing the accuracy of remote sensing image identification.

**Figure 9.** Comparison Map of thermal anomaly from Ts ASTER and Temperature Ground in Patuha area.

**Figure 10.** Comparison Map of thermal anomaly from Ts ASTER and Temperature Ground in Wayang Windu area.
4. Conclusions
The results of this study showed that satellite remote sensing is very useful in detecting and identifying areas of geothermal activity. Thus, remote sensing techniques provide a valuable tool for the identification of surface “hot spots” that have a high potential to serve as a geothermal energy source. There is a negative relationship between $T_s$ and vegetation cover. The higher the emissivity value shows the greater the energy emitted. It should be underlined that the emissivity of the object does not change if the object does not change. However, the problem here is not the availability of emissivity measurement tools. The overestimation of $T_s$ in Putih crater indicates the temperature from the water, and lower temperature from the ground where located around Putih crater. The other areas, $T_g$ is higher than $T_s$ ASTER and NDVI value $>0$. These areas may be areas that could potentially have geothermal energy. This indicate possible difference is caused by dense vegetation cover and resolution image of ASTER.

Acknowledgments
The authors sincerely thank to the “BAGUS” SATREPS project for providing field equipments, LPPM ITB for survey accommodation supports, and Star Energy for collaborating to this research.

References
[1] Barreto África Manuel Arbelo Pedro A Hernández-Leal Laia Núñez-Casillas María Mira and César Coll 2010 Evaluation of Surface Temperature and Emissivity Derived from ASTER Data: A Case Study Using Ground-Based Measurements at a Volcanic Site Journal of Atmospheric and Oceanic Technology 27 (10): 1677–88. https://doi.org/10.1175/2010JTECHA1447.1.

[2] Gillespie A S Rokugawa T Matsunaga J S Cothern S Hook and A B Kahle 1998 A Temperature and Emissivity Separation Algorithm for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Images IEEE Transactions on Geoscience and Remote Sensing 36 (4): 1113–26. https://doi.org/10.1109/36.700995.

[3] Jacob Frédéric Audrey Lesaignoux Albert Olioso Marie Weiss Karine Caillault Stéphane Jacquemoud Françoise Nerry 2017 Reassessment of the Temperature-Emissivity Separation from Multispectral Thermal Infrared Data: Introducing the Impact of Vegetation Canopy by Simulating the Cavity Effect with the SAIL-Thermique Model Remote Sensing of Environment 198 September 160–72. https://doi.org/10.1016/j.rse.2017.06.006.
[4] Kahle Anne B and Ronald E Alley 1992 Separation of Temperature and Emittance in Remotely Sensed Radiance Measurements Remote Sensing of Environment 42 (2): 107–11. https://doi.org/10.1016/0034-4257(92)90093-Y.

[5] Njoku Eni G ed 2014 Encyclopedia of Remote Sensing. Encyclopedia of Earth Sciences Series (New York, NY: Springer New York) https://doi.org/10.1007/978-0-387-36699-9.

[6] Saepuloh Asep Minoru Urai Nurmaning Aisyah Sunarta Christina Widwiyanty Subandriyo and Philippe Jousset 2013 Interpretation of Ground Surface Changes Prior to the 2010 Large Eruption of Merapi Volcano Using ALOS/PALSAR, ASTER TIR and Gas Emission Data Journal of Volcanology and Geothermal Research 261 (July): 130–43. https://doi.org/10.1016/j.jvolgeores.2013.05.001.

[7] Saepuloh A Suryantini Hecker C Hewson R 2017 Simulating Ground Thermal Anomaly under Conditions of Dense Vegetation Based on Lab and Field Measurements to Support Thermal Infrared Remote Sensing Techniques (Jakarta: Proceedings The 5th Indonesia International Geothermal Convention & Exhibition (IIGCE) August 2017)

[8] Suryantini Wibowo H Rahman K R Woldai T 2013 Application of Normalized Different Vegetation Index (NDVI) Method to Indentify Thermal Anomaly Area from Remote Sensing (Jakarta: Proceedings 3th Indonesia International Geothermal Convention & Exhibition (IIGCE) June 2013)

[9] Yamaguchi Y H Fujisada H Tsutsu I Sato H Watanabe M Kato M Kudoh A B Kahle and M Pniel 2001 Aster Early Image Evaluation Advances in Space Research 28 (1): 69–76. https://doi.org/10.1016/S0273-1177(01)00287-3.