Comparison of In-Situ Temperature and Satellite Retrieved Temperature in Determining Geothermal Potential in Jaboi Field, Sabang

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Abstract. Current technological advancement in remote sensing makes it possible to map potential geothermal hotspots for a large area effectively using thermal infrared sensors. However, in-situ ground temperature measurements are still needed to validate and support the land surface temperature results from remote sensing satellite images. The aim of this study is to compare in-situ temperature and satellite retrieved temperature in determining geothermal potential in Jaboi field, Sabang. The study was conducted in two phases by, firstly, using satellite Landsat 8 image and, secondly, in-situ survey. For the satellite image, Radiometric Calibration, Vegetation Index and Land Surface Temperature processes were carried out using Envi and ArcMap software. Meanwhile, temperature measurements from 114 in-situ sites around the survey area were recorded using Needle Probe Temperature device that was equipped with Arduino Uno as its microcontroller and 5 temperature sensors. Surface temperature in the Mount Jaboi ranges between 22°C to 29°C for satellite temperature and 25°C to 32°C for in-situ temperature. The temperature anomaly from ground measurements is observed to be consistent with high temperature anomaly from satellite retrieved temperature. This result suggests correlations between the estimated temperature from satellite image and ground measurements.

1. Introduction

Geothermal is a heat source that is trapped under the Earth’s crust. Based on its nature and geological setting, geothermal hotspots are usually located near seismically active area and along plate margins, where the subsurface temperature gradient is slightly above normal. Hot springs, fumaroles, volcanoes and many other geological thermal phenomena on the surface are the manifestation of the geothermal hotspots beneath the surface [1, 2, 3]. Geothermal system consists of the heat sources, reservoirs, a fluid which carries and transfer the heat, and recharge area through faults [3].

Indonesia lies along geological feature what known as “the Pacific Ring of Fire”. Along its archipelago, lie more than 200 volcanoes in which 129 of them are active with more than 500 volcano cones [4]. While all those volcanoes increase the risk of earthquakes and highly destructive area, it does give positive side such as high potential of geothermal energy. Due to its geological setting, Indonesia is considered as one of the countries with high potential in geothermal resources. Currently, Indonesia is fourth in the world for the geothermal resources with a total potential of around 27 GWe with 252 hotspots scattered along its archipelago [5].

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Current technological advancement in remote sensing makes it possible to map potential geothermal heat anomalies at a large scale effectively [6, 7, 8]. The relatively low cost, less time consumption and high observation accuracy makes it perfect as the first phase in exploration to supply data and information for further study. Landsat 8 is one of the many satellites that has the capability to give reliable information on surface temperature using thermal infrared sensors. Using Landsat 8, we can obtain vegetation density and retrieve land surface temperature which is useful in the determination of geothermal potential of the study area [9]. Although satellite imageries are effective, it is imperative that ground temperature measurements are carried out to validate the results from remote sensing.

The study area is located at the northern tip of Sumatra Island, Indonesia where Mount Jaboi is located. Geothermal Jaboi, Aceh is an active volcano located at the northern tip of Sumatra Island. The surface manifestation of its activity can be indicated by fumaroles, hot springs, hydrothermal altered area and hot mud [10]. Many research has been conducted to study the geothermal potential of the area [11, 12, 13]. The aim of this study is to compare in-situ temperature and satellite retrieved temperature in determining geothermal potential in Jaboi field, Sabang. Figure 1 shows the area of study. The study area took place in Mount Jaboi, Weh Island, Aceh, Indonesia. The mountain is located at about 10 kilometers south of Sabang city with coordinate of about 5°48'28.93"N and 95°19'44.88"E. The location of the mountain is denoted by U in the map below (Figure 1).

![Figure 1. Map of study area. The location of Mount Jaboi is denoted by U](image)

2. Data and Methods

2.1 Satellite Data Acquisition

A Landsat 8 imagery was downloaded from Earth Explorer - United States Geological Survey (USGS Earth Explorer - Website) with Path Type WRS 131 and Row 056. The date of acquisition of the imagery is July 18th, 2017. The projection of the imagery is UTM WGS84 Zone 46. Its spatial resolution is 30 meters for bands 1 to 7 and 9, 15 meters for band 8 (panchromatic) and 100 meters for bands 10 and 11 (thermal). Table 1 shows all the 11 bands that are contained in the downloaded data [14]. However, only bands 2, 3, 4, 5, 10 and 11 were used for analysis. This selection was made because bands 2, 3 and 4...
were used to produce true color image, band 4 and 5 were used for NDVI calculation and bands 10 and 11 are thermal bands that were used in the production of land surface temperature map.

| Bands                        | Wavelength (µm) | Resolution (meters) |
|------------------------------|-----------------|---------------------|
| Band 1 - Ultra Blue (coastal/aerosol) | 0.43 – 0.45     | 30                  |
| Band 2 - Blue                | 0.45 – 0.51     | 30                  |
| Band 3 - Green               | 0.53 – 0.59     | 30                  |
| Band 4 - Red                 | 0.64 – 0.67     | 30                  |
| Band 5 - Near Infrared (NIR) | 0.85 – 0.88     | 30                  |
| Band 6 - Shortwave Infrared (SWIR) 1 | 1.566 – 1.651  | 30                  |
| Band 7 - Shortwave Infrared (SWIR) 2 | 2.107 – 2.294  | 30                  |
| Band 8 - Panchromatic        | 0.503 – 0.676   | 15                  |
| Band 9 – Cirrus              | 1.363 – 1.384   | 30                  |
| Band 10 - Thermal Infrared (TIRS) 1 | 10.60 – 11.19  | 100 *(30)           |
| Band 11 - Thermal Infrared (TIRS) 2 | 11.50 – 12.51  | 100 *(30)           |

* TIRS bands are acquired at 100 meters resolution, but are resampled to 30 meters in delivered data product

2.2 Satellite Data Processing
Land surface temperature was retrieved from the satellite image by the following steps of processing using Envi version 5.3 software:
1. The image was cropped into the desired area as the downloaded image covered a wider region than the study area. With a smaller image, the processing can be more effective and less time consumed.
2. Radiometric correction was carried out to correct or reduce errors in the digital numbers of the downloaded image.
3. Normalized Difference Vegetation Index (NDVI) was calculated by using the following equation:

\[
NDVI = \frac{\text{NIR} - R}{\text{NIR} + R}
\]

Where in Landsat 8 OLI (Operational Land Imager), red band is band 4 and near-infrared band is band 5. From the calculated NDVI, the minimum and maximum values of NDVI were chosen. These values were used in determining emissivity when calculating LST later on.
4. Lastly, land surface temperature was retrieved by using thermal bands 10 and 11.

2.3 In-Situ Data Acquisition
In-situ temperature measurements were acquired using needle probe temperature device with a total of 114 points distributed evenly around the survey area. Figure 2 shows the design of the needle probe device used to record in-situ temperatures. Called LM35, the device is equipped with Arduino Uno as its microcontroller board and 5 pieces of temperature sensors mounted on a 2 meters iron rod. The LM35 measures the temperature around the sensors and the microcontroller processed the temperature values to be displayed on the LCD.
Figure 2. Design of needle probe temperature device [19]

The surface temperature is a thermal oscillation in the form of $T_0 \sin \omega t$ on a planar surface ($z=0$) and within a thermal diffusivity $\kappa$ on a semi-infinite medium, then the magnitude of the temperature amplitude can be determined after entering the medium [15].

$$T(z, t) = T_0 \exp \left( -z \frac{\omega}{2\kappa} \right) \sin \left( \omega t - z \frac{\omega}{2\kappa} \right)$$

When $T(z, t) = \frac{T_0}{e}$, temperature expansion occurs within the medium (skin depth).

2.4 In-Situ Data Processing

The In-situ temperature values were plotted into the map by using software ArcMap version 10.4 software. These values were saved as ASCII file format .txt with triple string of X and Y column for coordinates and Z for temperatures. The data were added into ArcMap which were then processed by using kriging tool to interpolate the temperature points and overlay the interpolated temperature map on Landsat 8 image to produce in-situ temperature distribution map of the survey area.
3. Results and Discussion

Figure 3 shows the study area after radiometric correction. This process needed to be done to correct or reduce errors in the digital numbers of the image before it can be processed further. NDVI map was generated using radiometric corrected image to determine the density of green vegetation on a patch of a land by measuring the difference between red spectrum which is absorbed by vegetation and near-infrared spectrum which is reflected strongly by vegetation. The bands used for the NDVI calculation are band 4 and band 5 for Landsat 8 imagery. Figure 4 shows the vegetation density map processed from Landsat 8 imagery. The NDVI values vary from -1 to 1. The higher the NDVI value, the denser the vegetation and vice versa. The threshold values for soil (< 0.5854) and vegetation (> 0.5854) were chosen based on the pixel’s brightness values from the NDVI image [16]. The study area has the highest vegetation index value of 0.8636 which indicates the most vegetated area where the lowest value is -0.5004 which indicates open water (Figure 4). Vegetation index has a very strong correlation with geothermal potential. The higher the vegetation index value, the lower the geothermal potential in the area [17].

Figure 3. Radiometric corrected image of the survey area

Figure 4. Normalized difference vegetation index (NDVI) image of the survey area
The minimum and maximum NDVI values were used to retrieve land surface temperature from the Landsat 8 imagery. Figure 5 shows the temperature distribution retrieved from Landsat 8 imagery around the study area. The lowest temperature is 22°C while the highest values is 29°C. The map shows several locations with high temperatures (>25.2°C). However, not all of them were considered as geothermal potentials, since some of the locations have man-made objects or are urban areas which are capable of giving high temperature when viewed by satellites [18]. The low temperature coincides with area with low vegetation index while high temperature coincides with low vegetation index. Figure 6 shows the temperature distribution that was acquired by needle probe temperature device around the survey area. The lowest temperature around the survey area is 25°C while the highest temperature is 32°C. The figure shows a possible geothermal hotspot showing a temperature anomaly in the south part of the island. This temperature anomaly is consistent with high temperature values from satellite-derived temperature map, which means that it shows appropriate correlations between the two temperature datasets [10].

**Figure 5.** Land surface temperature retrieved from Landsat 8 satellite imagery

**Figure 6.** In-situ temperature distribution acquired by needle probe temperature around survey area
4. Conclusion
The results of this study show the comparison of both in-situ temperature versus satellite retrieved temperature from Landsat 8 satellite imagery. The results show that there is a temperature anomaly at the southern part of the island indicating a possible area with geothermal activity. Finally, it shows appropriate correlation between the two temperature datasets, which proves that remote sensing is a reliable, cost-effective and fast method for preliminary geothermal exploration.

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References
[1] Hochstein, M. P., & Sudarman, S. 1993. Geothermal Resources of Sumatra. Geothermics 22: 181
[2] Risdianto, D., & Kusnadi, D. 2010 Proceedings World Geothermal Congress (Bali: Indonesia)
[3] Taquuddin, Z., Nordiana, M., & Rosli, S. 2016 International Research Journal of Engineering and Technology 4: 2234
[4] Ministry of Resources and Minerals. 2011. Geological Agency: Potential and Development of Geothermal Resources Indonesia, 2011. Annual Report of Geological Agency. Indonesia
[5] W. Resmiasih Mansoer, & Idral, A. 2015 Proceedings World Geothermal Congress (Melbourne, Australia)
[6] Hariyanto, T., & Robawa, F. N. 2016. Identification of Earth Potential Using Landsat 8 and Location Determination Generator Power Plant Power. Geoid. 12: 36
[7] Srivastava, P., Majumdar, T. 2010. Study of Land Surface Temperature and Spectral Emissivity Using Multi-Sensor Satellite Data. Journal of earth system science 119: 67
[8] Urai, M., Muraoka, H., & Nasution, A. 2002 Satellite remote sensing data and their interpretations for geothermal applications: A case study on the Ngada District, central Flores, Indonesia. Bulletin-Geological Survey Japan 53: 99
[9] Qin, Q., Zhang, N., Nan, P., & Chai, L. 2011. Geothermal Area Detection Using Landsat ETM+ Thermal Infrared Data and its Mechanistic Analysis – A case study in Tengchong, China. International Journal of Applied Earth Observation and Geoinformation 4: 552
[10] Isa., M. M. Z Mat Jafri and H. S. Lim, 2013 American Institute of Physics Conf. Proceeding (Collage Park: United State)
[11] Dirasutrisna, S., & Hasan, A. R. 2005 Geological Geology Geothermal Jaboi Sabang Nanggroe Aceh Darussalam Province. Report of the Directorate of Resources and Minerals. Thesis. Indonesia
[12] Widodo, S., Suhanto, E., & Kusnadi, D. 2006. Integrated geological, geochemical and geophysical survey in Jaboi geothermal field, Nanggroe Aceh Darussalam, Indonesia Report Geology – Ministry of Energy and Resource mineral Thesis. Indonesia
[13] Munandar, A., Boegis, Z., & Simarmata, R. S. 2007 Drilling grounds Wells Temperature JBO-1 and JBO-2 Geothermal Area Jaboi, P. Weh, Sabang–NAD Report Geology – Ministry of Energy and Resource mineral Thesis. Indonesia
[14] Landsat Mission | United States Geological Survey 2017 Retrieved on 24 December 2017, from https://landsat.usgs.gov/what-are-band-designations-landsat-satellites.
[15] Stacey, F. D., & Davis, P. M. 1977 Physics of the Earth. Second Edition, John Willey & Sons, Ltd. United States
[16] Hilmi, M. H., 2017 Integration of remote sensing and geophysical data in detecting geothermal potentials in Ulu Slim, Perak. Thesis. Malaysia
[17] Sukojo, B., & Mardiana, R. 2017 *IOP Conference Series: Earth and Environmental Science*. 98 012014

[18] Qiming, Q., Ning, Z., Peng, N., and Leilei, C. 2011 *International Journal of Applied Earth Observation and Geoinformation* 13: 552

[19] ASTM D 1995 5334 *Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure*. West Shonohoken : Annual Book of ASTM Standards