Identification of non-volcanic geothermal manifestation in North Konawe Regency Indonesia using land surface temperature of Landsat satellite image

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Abstract. Energy needs are increasing from year to year. However, in many countries, fossil energy is utilized in a large portion even though the country has a lot of potential for new and renewable energy. Geothermal is renewable energy has an important role in Indonesia besides other potential renewable energy such as water, wind, solar, and ocean tidal. This study aimed to identify non-volcanic geothermal manifestation in North Konawe Regency, South East Sulawesi Province, based on Landsat Enhanced Thematic Mapper (ETM) remote sensing satellite image. Land Surface Temperature (LST) method was conducted using thermal band processing of Landsat ETM. For this purpose, the single-window algorithm was applied. Validation was also conducted through a ground survey. The result of this study showed that at least two geothermal manifestations were founded in two separate locations in Wawolesea village and Toreo respectively. From the LST analysis, we found that the temperature reached 26.35 to 37.42 Celsius Degree in both locations, where hot water spring as geothermal manifestation exist. According to the ground check, the temperature correlation between in situ and LST is enough which $R^2=0.5155$.

1. Background

Geothermal energy is one of the most popular sources of energy today because fossil energy is decreasing and is rarely found. The geothermal is friendly renewable energies with huge potential in Indonesia besides water, wind, solar, and ocean tidal. Indonesia has the largest geothermal potential in the world, reaching up to 40% of world reserves or about 27,000 MW to 29,000 MW. However, at present, only 4.2% or 1,226 MW of existing reserves the geothermal energy potential is utilized in Indonesia [1]. This means a larger portion of geothermal energy resources still laid untouched beneath the islands of Indonesia. There is no further utilization of geothermal in the new geothermal activity areas [2].

The sources of geothermal can be divided into two groups. Firstly, the volcanic belt geothermal sources. Such geothermal sources spread from Sumatra, Java, Bali, Nusa Tenggara Barat, North Sulawesi to North Maluku Island. Secondly, are non-volcanic geothermal sources spread in Bangka-Belitung, West Kalimantan, South Sulawesi, Southeast Sulawesi, Central Sulawesi, Maluku, and Papua Islands [2].

Southeast Sulawesi regions are close to the ring of fire of Sulawesi Island. Southeast Sulawesi also lies in the Palu-Koro fault track that stretched from the Central Sulawesi-Southeast Sulawesi-Banda Sea. Among 252 available geothermal locations, only 31% of them had been thoroughly surveyed and identified as deposits. In most locations, mainly located in the remote areas are still in the preliminary survey status, so that resources’ potency is yet to be exactly found [3]. The development of existing
geothermal energy opposite to Indonesia’s western areas was all taken place in volcanic environmental areas [4].

In the early geothermal exploitation, several data should be available to begin the exploration stage. Beside geophysical and geology data, it is needed the map the entire presumed geothermal area [17-18]. To produce the entire condition such as topography, land use, and land cover, and spectral characteristics of the area, including the ground deformation, the satellite image is used [20]. The land use and land cover map give information about the geothermal area’s spatial characteristics such as vegetation density, settlement distribution, infrastructure, and so on.

However, the most important information in the exploration stage can be given by the satellite image’s spectral data. The spectral characteristic can give information about the manifestation of geothermal at a certain location. Some satellite images can be used to do this task such as Landsat or ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer). Remote sensing and satellite image processing method are reliable, fast, and effective enough to be used in various applications. Lanshin and Al-Arifi (2012) research has revealed the data processing speed to obtain geothermal potential area characteristics using remote sensing satellite imagery [6]. Research using remote sensing data to investigate potential characteristics and geothermal area monitoring was carried out by many scientists worldwide, for example, Savage (2009) using LANDSAT to map heat flow in geothermal areas [7]. Other research uses the SPOT satellite image by Kervyn et al. (2007) with a better spatial resolution compared to LANDSAT to map any distinct geological characteristics [8]. Calvin et al. (2002), Enerv et al. (2006), and Kratt et al. (2009) use ASTER hyperspectral satellite imagery by taking advantage of its thermal infrared waves [9-11].

Thermal sensors or scanners detect emitted radiant energy from sources. Due to atmospheric effects these sensors usually operate in the 3 to 5 μm or 8 to 14 μm range. Most thermal remote sensing of Earth features, like the sensor used in this research, is focused in the 8 to 14 μm range because peak emission (according to Wien's Law) for objects around 300K (27 °C or 80 °F) occurs at 9.7μm [12]. The research concluded that thermal band can be used in the future to reveal characteristics and monitor geothermal presence.

This research aims to map non-volcanic geothermal manifestation in North Konawe District South East Sulawesi Province using Landsat ETM (enhanced thematic mapper) satellite image.

2. Methods

2.1 Location

Geographically, the study locations are situated within coordinates of 3º41’51” S and 122º18’08” E. This area is located administratively in Lasolo Sub District, North Konawe District (Wawolesea Village and Toreo). The location map and situation in the study location can be seen in Figure 1.

2.2 Data

In this study, we used Landsat ETM images in 2003 and SPOT imagery in 2009. The use of 2003 Landsat imagery was intended to look at the condition of geothermal locations around 17 years ago and can be used for further studies by comparing them with 2020 Landsat 8 image data in subsequent studies.

2.3 Single window Algorithm

A single window algorithm was used to calculate the Land Surface Temperature (LST). LST can be defined as the radiative skin temperature of the land derived from solar radiation. A simplified definition would be how hot the “surface” of the Earth would feel to the touch in a particular location [19].

The LST calculation algorithm can be derived as:

a. Digital number conversion to spectral radiance (RADIANCE), with the equation:

\[ \text{RADIANCE} = \frac{(\text{LMax}_\lambda - \text{LMin}_\lambda)}{\text{QCalMax}-\text{QCalMin}} \times \text{QCal} - \text{QCalMin} + \text{LMin}_\lambda \]  

where:

- \( \text{QCal} \) : Digital Number
- \( \text{LMin}_\lambda \) : Radiance Spectral Scale of QCalMin
- \( \text{LMax}_\lambda \) : Radiance Spectral Scale of QCalMax
- \( \text{QCalMin} \) : Calibrated pixel minimum number (=1)
- \( \text{QCalMax} \) : Calibrated pixel maximum number (=255)
b. Spectral radiance (L) conversion to temperature (in Kelvin) with the equation:

\[ T = \frac{K_2}{\ln\left(\frac{K_1 \cdot \varepsilon}{RADIANCE} + 1\right)} \]  

(2)

where:

- \( T \): Satellite effective temperature in Kelvin
- \( K_2 \): Calibration 2 constants (For LANDSAT ETM+ valued 1282.71)
- \( K_1 \): Calibration 1 constants (For LANDSAT ETM+ valued 666.09)
- \( \varepsilon \): Emissivity (valued 0.95)

Figure 1. Location of the study (left) and condition in the geothermal manifestation (right): A and B situation on geothermal manifestation in Wawolesea Village while C and D in Toreo Village

3. Results and Discussion

3.1 Ground Characteristics

We started to characterize the presume geothermal location using the SPOT (Satellite Pour l’Observation de la Terre) image (Figure 2 B and C). SPOT XS (Multi-spectral SPOT) consists of four spectral bands: near-infrared, red, green, and panchromatic. Panchromatic image used in the spectral analysis since it has a 10-meter spatial resolution and RGB band 1-2-3 composite with 20-meter
resolution. With a multispectral spatial resolution of 10 meters, the SPOT XS image can detect surface runoff from geothermal manifestations via blue waves. Thus, the mapping of geothermal areas can be done better.

From the SPOT XS image, we also obtained the spatial-spectral of the land cover picture of the location which showed geothermal location’s topographical border. The tone is near to white color influenced by the hotter temperature rather than the border. The seawater at the upper right of the image is black which is influenced by a transmitted wave into the water. This picture can give us a comprehensive figure of the geothermal location in a fair spatial resolution.

Figure 2 A and D are produced from Landsat TM image. Figure 2 A is a panchromatic band with a 15-meter spatial resolution while Figure 2 D is a natural color composite RGB Bands 5-4-3 with 30-meter resolution. Both Landsat TM Panchromatic Imagery and SPOT XS, Wawolesea area looks bright because of the reflected electromagnetic wave by limestone (Calcium Carbonate) that dominate the area. The open areas are shown as brightly red on Landsat natural color composite, while the hot water spring would be observable as blue.

Figure 2. Geothermal Areas Satellite Imagery (A) LANDSAT TM Panchromatic spatial resolution of 15 meter (B) SPOT XS panchromatic imagery 10-meter spatial resolution. (C) RGB 123 composite imagery of SPOT XS 20-meter spatial resolution. (D) RGB 543 Landsat ETM composite imagery 30-meter spatial resolution

3.2 Land Surface Temperature

Lands Surface Temperature (LST) is a highly important parameter that controls longwave radiation changes and heat fluxes between the surface and atmosphere [13]. Remote sensing satellite imagery such as LANDSAT TM or ETM has been used by many scientists worldwide to map geothermal potency using single-channel algorithm methods [14,15].

The presence of geothermal in a particular place can be identified through the existence of several objects such as hot springs, hot or warms grounds, gas emission from the subsurface, hot mud, etc [16]. The hot conditions on the surface are then recorded by sensors mounted in remote sensing satellites.

Remote sensing satellite imagery has an infrared thermal spectrum that holds information about land temperature in the form of digital numbers (DN) ranged between 0-255 (8 bit). Digital number initially converted to radian values by calculating bias and gain values of a certain band in satellite imagery utilized in the processing. Then by taking into account the atmospheric correction of satellite imagery, we may obtain more accurate radian values. As the final stage, the digital number’s value conversion to
thermal values with Kelvin or Celsius was conducted to observe the Land surface temperature (LST) distribution.

Figure 3 displays the LST distribution in the study location obtained from thermal band processing. The surface temperature values obtained in Wawolesea and Toreo geothermal area and surroundings varied between 26.35 °C to 37.42 °C. The highest temperature (about 37 °C) is observed by its spatial distribution in the coastal area where the manifestation is situated. According to ground check, we found that geothermal manifestation in the form of hot spring was distributed in several locations. On the other side, we also obtained the lower temperature (for example 26.35 °C) located outside the hot spring such as the vegetation or open bare surface.

The result obtained from LST then compared to actual or in situ temperature obtained using thermometer measurement. For in situ temperature, we obtained that the temperature also varies between 30.2 °C outside of the hot spring and about 65.5 °C in the hot spring. The result may far different since the thermal band obtained the upper temperature above the ground, during the in-situ measurement directly from the hot spring.

The calculation results show that the detectable temperature range is up to 37.42 °C. This is because the thermal sensor detects the temperature above the geothermal surface and not exactly at the geothermal manifestation itself. This is a limitation of active sensors in most optical images including Landsat, SPOT and so on. Therefore, it is impossible to obtain a factual temperature based on the image, so a validation or ground check is needed to determine the temperature correlation between the image and the actual surface.

Another interpretation of the LST lower than the actual temperature is regarding the spatial resolution of the thermal band of Landsat TM which 120 m. This is not enough to map the entire ground temperature in detail. However, the LST result is satisfying enough to see the characteristics of geothermal potency distribution in the study location.

According to ground check, the correlation between LST and actual measurement of ground temperature is fair enough. This can be seen through the $R^2=0.5155$. The in-situ temperature is about 30.2 to 65.5 °C. Figure 4 shows the correlation between LST and in-situ measurement. However, the temperature is lower than the expected geothermal temperature for exploration which above 90 °C.
Figure 4. Correlation between LST and in-situ measurement

4. Conclusions and Suggestions

4.1. Conclusions
We have conducted the research to map the potency of geothermal in non-volcanic area in Southeast Sulawesi. The presume geothermal area consists of about 300 ha according to the delineation of SPOT XS satellite image. The area has a specific ground characteristic with land use and land cover varies from bare soil, rare-vegetated area, shrubs, settlement, field, and forest. Based on the LST map, the geothermal potency is located along the coastal line of Lasolo district particularly in the Wawolese and Toreo Village. The manifestation of geothermal potency in these villages are hot spring. The temperature of LST indicated between 26.35 to 37.42 °C while in situ temperature lies between 30.2 to 65.5 °C. Based on the ground check, the temperature correlation between in situ and LST is enough which $R^2=0.5155$.

The correlation value obtained in this study shows that the temperature obtained from the Landsat ETM thermal band has a fairly correlation with the actual temperature in the field. However, it should also be noted that the difference in observation time between the satellite and the ground check is a factor that causes the correlation not to be as expected. Further research needs to be carried out by involving the satellite imagery that was acquired simultaneously with the ground check, although it is quite difficult to do. Cloud cover in the equatorial region including at the study site needs to be considered.

4.2 Suggestions
From the above result, some suggestions can be proposed as follow:

1. This research still need to broaden especially with additional geochemistry and geophysical aspects to enrich spatial data of potential geothermal areas, for example, to determine the certain mineral presence in the area
2. Considering the vast area of observation size, which more than 300 hectares, intensive study to reveals the actual potency of geothermal areas in Wawolesea and Toreo village will be required. The existing geothermal sources maybe only a portion of larger geothermal sources in the area.
3. Due to the lower temperature below the optimum temperature for geothermal exploitation, we suggest it be designed as a location for the tourism area, spa, and edu-tourism. This is more valuable in the future to exploit this area.

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