Proceedings World Geothermal Congress 2023
Beijing, China, April 17 – 21, 2023

NDVI Method to Identify Thermal Anomaly Area Using Sentinel Imagery

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Keywords: NDVI, Sentinel 2, vegetation stress, thermal manifestation, Sirung area

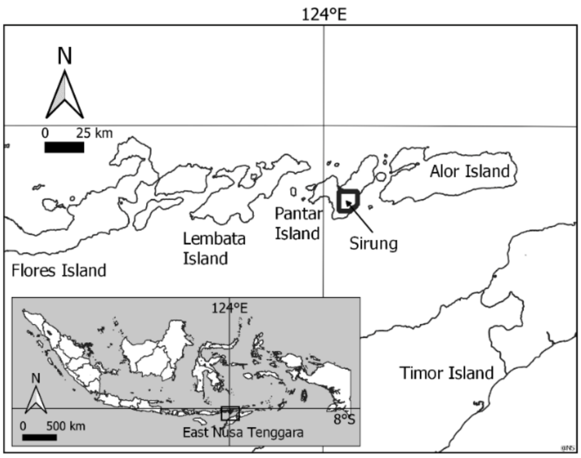
ABSTRACT

Normalized Difference Vegetation Index (NDVI) has been used as one of exploration tool in geothermal area selection, especially in heavy vegetation area. It is used based on unhealthy characteristics of stressed vegetation which is assumed to be caused by geothermal activities such as excess heat and/or more acidic environment in geothermal area. Those environments affect vegetation into stress condition that tend to reflect more visible light and less near-infrared light in remote sensing, which are reflected in the NDVI map. Low NDVI area may associate to geothermal manifestation such as altered ground, thermal manifestations or warm ground. This paper use Sentinel 2 satellite with multispectral images of 10 and 20 meter spatial resolutions that could provide more detailed target area, compared to Landsat 30-meter resolution. A case study in Sirung area of volcanic high terrain geothermal setting is used to show that surface manifestations of hot ground are mapped. Subtler variations and anomalies can be expected that may assist further exploration survey activities. Sentinel 2 NDVI provides higher resolution and more detailed information. It provides comparable consistent anomaly location with Landsat 8. Ground interpretation from Sentinel 2 may provide more accurate information on thermal anomaly pattern and extent, that can also assist in further planning of geological, geochemical and geophysical survey design.

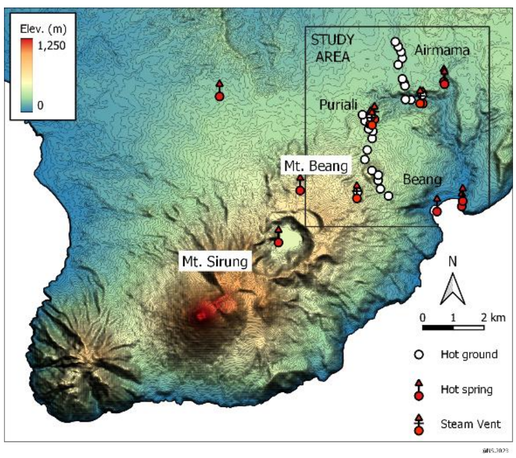
1. INTRODUCTION

Normalized Difference Vegetation Index (NDVI) has been used as one of exploration tool in geothermal area selection, especially in heavy vegetation area (Suryantini et al., 2013). It is used based on unhealthy characteristics of stressed vegetation which is assumed to be caused by geothermal activities such as excess heat and/or more acidic environment in geothermal area. Those environments affect vegetation into stress condition that tend to reflect more visible light and less near-infrared light in remote sensing. This characteristic is reflected in NDVI map which can then be used to assess field condition that may be associated to geothermal manifestation such as altered ground, thermal manifestations or warm ground (Suryantini et al., 2013).

This study applies NDVI, constructed from Sentinel 2 data, in activity of early geothermal exploration stage at Sirung geothermal area (Figure 1a). Volcanic activities in Sirung area began from Tertiary to Early Quaternary (Hadi and Kusnadi, 2015). Volcanism in this sub-epoch range is characterized by major events in the form of calderas formed as a result of major eruptions. The tectonic traces produced two array faults, which develop in Puriali and Kuaralau area. Young volcanism is dominated by effusive deposits in the form of andesite-basalt lava flows and the Reng Ara Lava Dome and the Beang Lava Dome. This young volcanism also produced explosive deposits at medium to large levels. Evidence from the traces of a major eruption was obtained through geophysical analysis in the form of a circular feature suspected of being a caldera. The active volcanism of the Mount Sirung complex is the main manifestation of geothermal system found at low elevation ground in north-eastern part of Mount Sirung (Figure 1b). The thermal manifestations surface as north-south trend of steam vents and hot grounds with temperatures >70°C. In addition, several hot springs and warm springs were also found in this area.



a) location map



b) study area

Figure 1. Sirung geothermal area in Pantar Island at East Nusa Tenggara Province, Indonesia

2. THEORY

Remote sensing studies use data gathered by satellite sensors that measure wavelengths of light absorbed and reflected by green plants. Certain pigments in plant leaves strongly absorb wavelengths of visible (red) light. The leaves themselves strongly reflect wavelengths of near-infrared light. Vegetation indices such as NDVI can be constructed from satellite images that give a rough measure of vegetation type, amount, and condition on land surfaces. It is by exploiting these characteristics that NDVI is used in geothermal exploration activities to map ground conditions. Significant stressed vegetation in geothermal area may be caused by high temperature, low pH, thermal activities such as fumaroles and its condensation product (Suryantini et al., 2013). Thus, very low NDVI anomalies could be associated with geothermal activities.

NDVI index is obtained by calculating ratio between visible red (Red) and near-infrared (NIR) band, i.e., NDVI = (NIR – Red)/(NIR + Red). NDVI values range from +1.0 to -1.0. Areas of barren rock usually show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs and grasslands or deteriorating crops may result in moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation (USGS, 2022b).

3. DATA

This study used Sentinel 2 and Landsat 8 data. Sentinel 2 is used as the main data whereas Landsat 8 is used as comparison.

3.1 Sentinel 2

Sentinel 2 satellite data were obtained from European Space Agency (ESA, 2022). The one that is selected for this paper is acquired at 27 July 2021 in equatorial dry season when the sky is clear. The data contain multispectral imagery bands with spatial resolution of 10 to 60 m in the visible, near infrared (VNIR), and short-wave infrared (SWIR) spectral zones, including 13 spectral channels (Figure 2), which ensures the capture of differences in vegetation state, including temporal changes, and also minimizes impact on the quality of atmospheric photography.

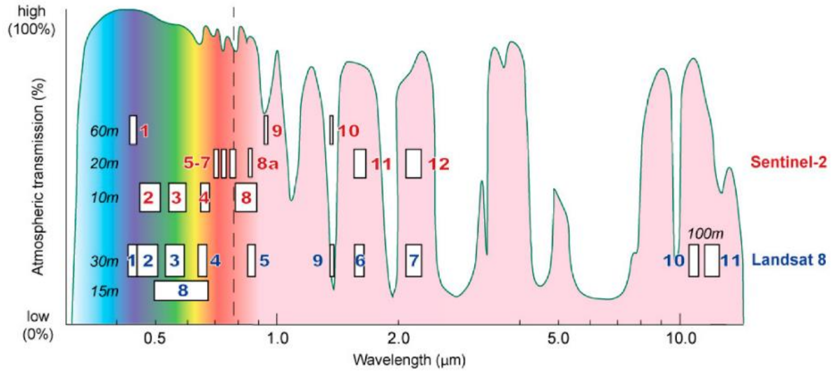


Figure 2. Sentinel 2 data spatial and spectral characteristics (upper part of the figure)
in comparison to Landsat 8 (lower part of the figure) (Source: Kääb et al., 2016).

The Sentinel 2 data used in this study is at Level-2A processing includes a scene classification and an atmospheric correction applied to Top-Of-Atmosphere (TOA) Level-1C orthoimage products. Level-2A main output is an orthoimage Bottom-Of-Atmosphere (BOA) corrected reflectance product (ESA, 2022).

3.2 Landsat 8

Landsat 8 satellite data were obtained from NASA (USGS, 2022a). The one that is selected for this paper is acquired at 2 August 2021 in close date to Sentinel 2 data above. The data contain multispectral imagery bands with spatial resolution of 15, 30, and 100 m in the visible, near infrared (VNIR), short-wave infrared (SWIR), and Thermal infrared (TIR) spectral zones, including 11 spectral channels.

The Landsat 8 surface reflectance data used in this study is Collection 2 Level-2 Science Products. The LEDAPS and LaSRC surface reflectance algorithms correct for the temporally, spatially and spectrally varying scattering and absorbing effects of atmospheric gases, aerosols, and water vapor (USGS, 2022c).

4. METHODOLOGY

NDVI method is applied using Sentinel 2 bands, that is **NDVI = (band 8 – band 4)/(band 8 + band 4)**. NDVI map of study area will be analyzed and compared to the location of surface manifestation. Image of True Color Composite (RGB band 4,3,2) will serve as contextual information and can sometimes identify unwanted "false" anomalies (e.g., low NDVI anomalies resulted from man-made features such as houses and roads).

In this study, the availability of surface thermal manifestations serves as ground truths in interpreting remote sensing NDVI image of Sirung geothermal area. The NDVI anomalies are used as a proxy for spatial extent interpretation of geothermal area.

The effect of ground resolution in this study is also analyzed by comparing NDVI of Sentinel 2 to NDVI of Landsat 8. The NDVI of Landsat 8 is calculated using its corresponding visible and NIR bands, that is **NDVI = (band 5 – band 4)/(band 5 + band 4)**.

5. RESULTS

Figure 3 shows topography digital elevation model where locations of hot springs, steam vents, and hot ground are shown. Hot springs are located at Beang coastal area in the south and at Kuralau ravine. A group of hot ground manifestations are located at Airmama area (Figure 4a) in the north. Their appearances in the ground are shown as burned rock/soil and whitish/greyish vegetation. These manifestations are found near topographical scarps shown at Figure 4b. Those topographical scarps may indicate possible north-south structurally control trend. Another north-south trend group of hot ground are located in the southern area, from Puriali area to the south that includes crossing the hill of Mt. Beang (Figure 3). Figure 5 shows hot ground surface manifestation at Mt. Beang.

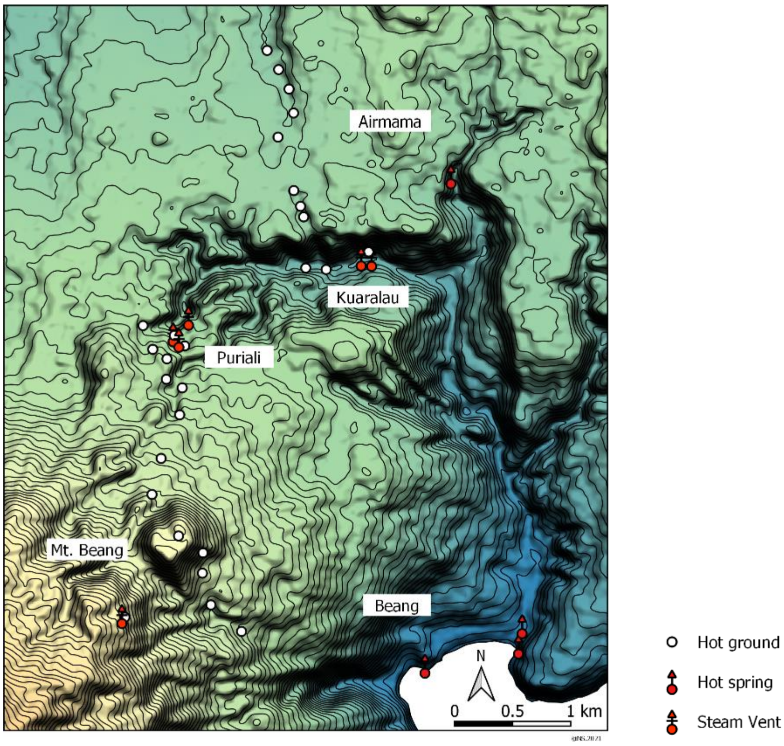


Figure 3. Digital elevation model with location of hot springs, steam vents, and hot grounds.

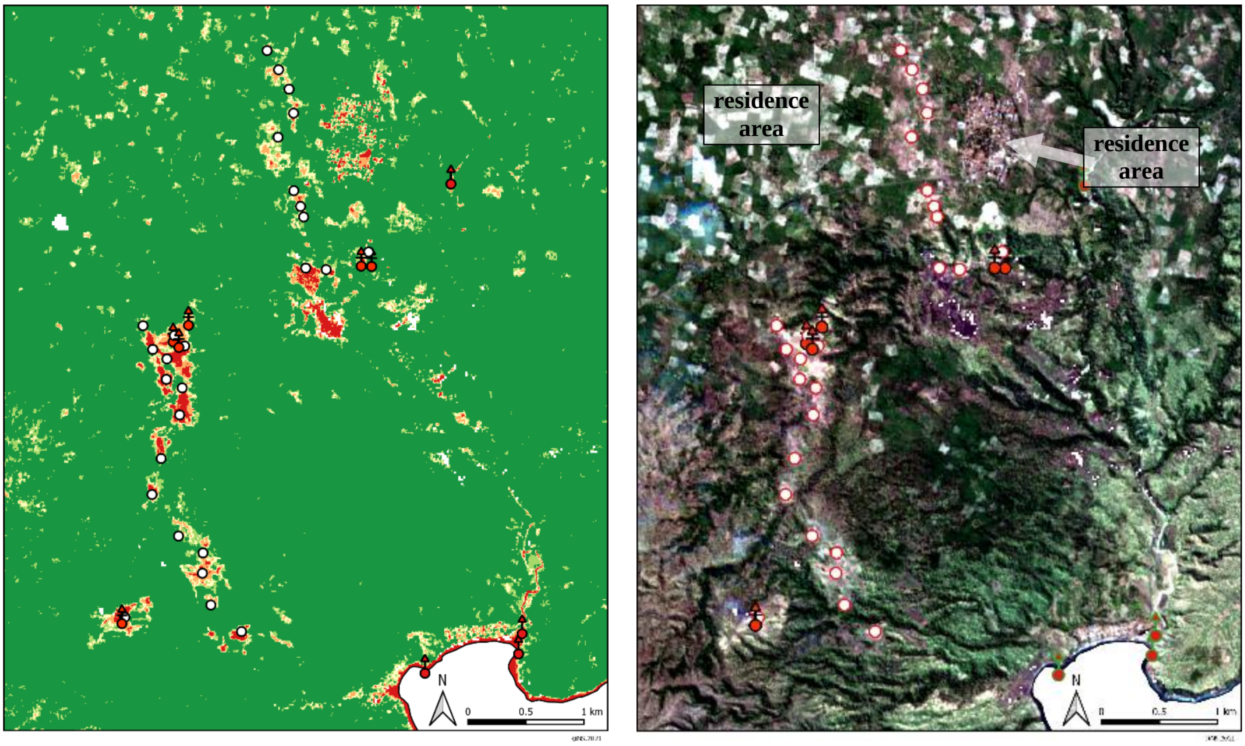
a) hot ground b) topographical scarp

Figure 4. a) Hot ground manifestations at Airmama area, and b) topographical scarp site

Figure 5. Hot ground manifestations at Mt. Beang hill

The NDVI map of Sentinel 2 is shown at Figure 6a, where anomaly thresholds and classifications used in this study are customized (using trial and error method) to enhance and focus into possible thermal activities affected area (Suryantini et al., 2013). NDVI anomalies that are observed in Figure 6a but are located within populated village/residence area in Figure 6b are ignored during the analysis.

NDVI in Figure 6a shows north-south trend of low anomalies values where hot ground manifestations are found in the field. Sentinel 2 true color composite image is shown in Figure 6b indicating less vegetated and bare ground area in those low NDVI anomalies. The pattern of red color anomalies (low NDVI values) may provide important spatial extent interpretation for geothermal energy exploration. These are the areas that could be investigated further for evidence of altered ground that may associate with high temperature and low pH, which may characterize an upflow zone.



a) NDVI

b) True Color Composite (TCC)

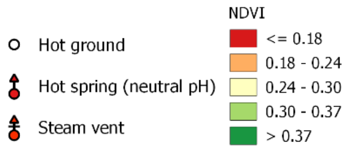


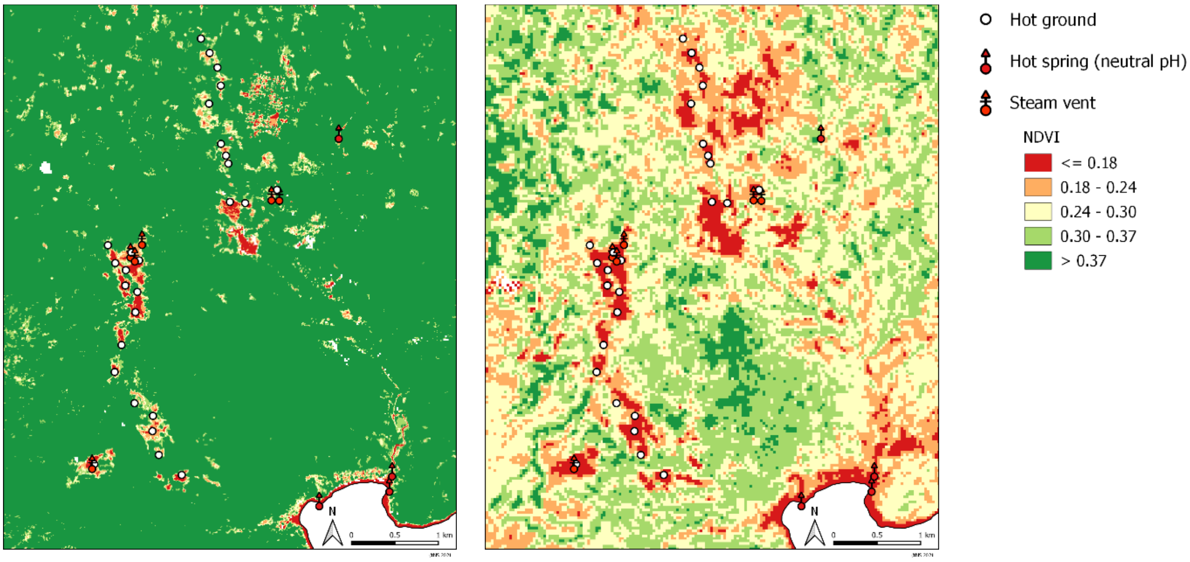
Figure 6. Sentinel 2 a) NDVI and b) TCC images. Hot springs (red circle with arrow) and hot grounds (white circle) are shown, populated area is indicated and labeled in TCC image.

6. THE EFFECT OF GROUND RESOLUTION

During the development of Landsat 8 and Sentinel-2A, calibration scientists from both projects worked together to cross-calibrate the sensors (USGS, 2022d). Many scientists and researchers are looking forward to collectively using data from Landsat 8 and Sentinel-2A. Thus, differences between the two are expected mainly related to different spatial resolution, and then differences due to acquisition time, weather, landcover changes. Sentinel 2 bands are 10 m in ground resolution, whereas Landsat 8 is 30 m. Thus, one pixel in Landsat 8 is represented by 9 pixels in Sentinel 2. This will reflect the detail of the Sentinel 2 image and later the accuracy of the interpretation.

In the study area, the differences are demonstrated in Figure 7. Figure 7a on the left is NDVI image generated from Sentinel 2 data and Figure 7b on the right is from Landsat 8 data. Both are acquired practically at the same time (~2 weeks apart) at equatorial dry/hot season when the sky is clear. As mentioned previously, anomaly thresholds and classifications used in this study are manually customized to enhance possible affected thermal related area, thus NDVI color scale in Figure 7 also shows narrow value ranges at the low end of NDVI values. Sentinel 2 data should provide more detailed and accurate pattern, while the one generated by Landsat 8 will show averaging effect between adjacent pixels.

Although anomaly patterns of interest (low NDVI values related to hot grounds) and their locations in both images are comparable, there are several false anomalies appear at NDVI from Landsat 8 image, while Sentinel 2 give more accurate information. In Sentinel 2, human populated area in the northern part (Airmama area) is not depicted as red (low NDVI values) as in Landsat 8. Thermal anomalies of hot grounds are consistently and arguably better outlined compared to the ones in Landsat 8. Thus, higher resolution provide more accurate interpretation of thermal anomaly extents and might ensure additional certainty. This kind of information can help in better logistics and planning field investigations, but the most significant advantage is for effectiveness in planning geological, geochemistry and geophysical survey designs.



a) Sentinel 2 (27 July 2021) b) Landsat 8 (2 August 2021)

Figure 7. NDVI produced by a) Sentinel 2 and b) Landsat 8.

7. CONCLUSIONS

Application of NDVI method in early stage of geothermal alteration is very useful. The area with low NDVI value may be suspected as the area with vegetation stress due to a process related to hydrothermal fluid activities. However, careful analysis of the cause of NDVI anomaly must be applied throughout interpretation process, by considering morphology, clouds, and manmade features. Very low NDVI anomalies (red color in this study) are mostly associated with hot grounds and are located in interpreted structural geology, indicated by topographical scarp. These anomalies may be associated with high temperature and/or low pH caused by thermal activities. These activities affected fertility of plants resulting in stressed vegetation.

Sentinel 2 NDVI provides higher resolution and more detailed information. It provides comparable consistent anomaly location with Landsat 8. Ground interpretation from Sentinel 2 may provide more accurate information on thermal anomaly pattern and extent, that can assist in further planning of geological, geochemical and geophysical survey design.

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