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APPLICATION OF NORMALIZED DIFFERENT VEGETATION INDEX (NDVI) METHOD TO IDENTIFY THERMAL ANOMALY AREA FROM REMOTE SENSING

Suryantini [1) 2)], Hendro Wibowo [1)], Khalif R. Rahman [1)], Tsehaie Woldai [3)]

1) Program Studi Magister Teknik Geotermal FTTM,
2) Program Studi Teknik Geologi FITB,
Institut Teknologi Bandung (ITB), Jl Ganesha 10, Bandung 40132
3) ITC Faculty of Geo-Information Science and Earth Observation of the University of Twente
PO Box 217, 7500 AE Enschede, The Netherlands

e-mail: suryantini@gc.itb.ac.id

ABSTRACT

Normalized Different Vegetation Index (NDVI) is calculated from satellite image, i.e. the visible and near-infrared bands where sun rays are reflected by vegetation. Healthy vegetation absorbs most of the visible light, and reflects a high portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light.

In geothermal area, the occurrence of thermal manifestation often causes the vegetation stress due to acid fluid or high temperature. By mapping the area with low NDVI value that indicates vegetation stress, the potential area of manifestation, even for concealed features, may be delineated.

Case studies in several volcanic high terrain geothermal areas show that NDVI can assist early identification of thermal manifestation area, guiding the geothermal area selection. However interpretation of the cause of low NDVI value must consider the concept of geothermal system and the man-made feature that can lead to misinterpretation.

Keyword: NDVI, thermal manifestation, volcanic associated geothermal system, geothermal area selection

INTRODUCTION

Exploration of Geothermal Energy always involves sampling program of thermal manifestation such as fumaroles, springs or pools. The occurrences of thermal surface manifestations are often used to locate the boundary of a geothermal system, in particular at the early stage of exploration such as during preliminary survey. On the other hand, identifying active surface manifestation in a highly dense vegetated area is difficult because the manifestations are often covered by vegetation. This condition is worse where the thermal manifestation occurred as a concealed outflow and emerges as seepage.

In a high temperature geothermal system (T>225^{o}C), the surface manifestation are mostly associated with intense discharge features such as fumaroles, hot springs, or acid water. These features may produce strong rock alteration at its paleo-surface or emerge as warm slightly acid springs in the outflow zone. The area of intense and active thermal manifestations and their associated products are able to cause the soil or the ground become infertile due to high temperature and very low pH. Thus, the vegetation are barely live in this area, or if it could live, the vegetation will grow as unhealthy or "stressed".

Vegetation stress are usually manifested in the leaf by showing color other than green, e.g. red, orange, yellow, brown, or by the limited number or lack of leafs in the plant. Unlike some active thermal features which occur in a very small and limited area, for instance hot springs in few cm square or altered ground which covers tens of meters square, vegetation stress may cover much larger area. Thus, it may be possible to detect those stress features using remote sensing data. A careful investigation of vegetation stress features in a geothermal area could provide a tool for locating possible active thermal surface manifestation for further ground truth examination, and furthermore may delineate the geothermal system extent.

This paper discusses the application of remote sensing technique, namely Normalized Different Vegetation Index (NDVI) to delineate anomaly area of vegetation stress. The result of NDVI anomaly

area is then compared with the occurrence of active surface manifestation and a conceptual model of high terrain, high temperature geothermal systems to determine the cause of the anomaly. Later, it is used to delineate prospect areas for further exploration program.

THEORY

Unhealthy, stressed vegetation that shows leaf color other than green reflects more visible red light and less near-infrared light of the electromagnetic (EM) spectrum. In contrast, green and healthy vegetation absorbs most visible red light and reflect high portion of near-infrared light.

The NDVI is calculated by taking the advantage of the ratio between reflected and absorbed light in the EM spectrum wavelength: visible red and near-infrared range. Uses of NDVI was started as far back as 1969 by NASA to simply and quickly identify vegetated areas and their "condition", using Landsat multispectral remote sensing data (wikipedia.org). The formula to calculate NDVI is shown below:

$$NDVI = \frac{Infrared\ band - Visible\ red\ band}{Infrared\ band + Visible\ red\ band} \quad \text{Eq. 1}$$

Visible red and near-infrared wavelength are in the range 0.63-0.69 µm and 0.76-0.90 µm respectively. These correspond to Band 3 and Band 4 in Landsat Thematic Mapper (TM) 7 Satellite. Using Landsat TM/ETM+, the previous formula will correspond to:

$$NDVI\ TM = \frac{TM\ band\ 4 - TM\ band\ 3}{TM\ band\ 4 + TM\ band\ 3} \quad \text{Eq. 2}$$

Healthy vegetation will have NDVI ratio between positive 0.3 and 0.8, while significantly stressed vegetation and bare ground will have NDVI ratio less than 0.1 or even minus value. Between these two classes lies slightly stressed vegetation group.

NDVI method can also be applied using data from other satellite and sensor such as ASTER (Advance Spaceborne Thermal Emission and Reflection Radiometer) . 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 µm in band 3. The equivalent NDVI formula using ASTER data is as shown in Equation 3:

$$NDVI\ ASTER = \frac{ASTER\ band\ 3 - ASTER\ band\ 2}{ASTER\ band\ 3 + ASTER\ band\ 2} \quad \text{Eq. 3}$$

DATA AND METHODOLOGY

For the purpose of this research, NDVI from five geothermal areas in Western Java are calculated. The study areas are Tangkuban Perahu, Tampomas, Ciremai geothermal prospect area, and Kamojang, Wayang Windu geothermal plants, shown in Figure 1.

NDVI is calculated on Landsat data with 30 m ground resolution. The Landsat ETM+ data for research study area was covered in 2 scenes and acquired on 1999 and 2005, with relatively cloud free. NDVI is also calculated with ASTER data for Tangkuban Perahu area, with 15 m ground resolution. Those different ground resolutions between Landsat and ASTER will give impact on the detail of the NDVI map produced, and will be demonstrated later with the case study in Tangkuban Perahu area.

The resulted NDVI map for each study area will be compared with the location of surface manifestation. Image of True Color Composite (RGB of Landsat band 3,2,1) will serve as spatial reference and contextual information, as this color combination resemble closely what would be observed by human eyes, i.e. visible color photograph image.

NDVI anomaly areas are analyzed based on those data. Later, knowledge of morphology and concept of high temperature – high terrain geothermal system is applied for better understanding on the probable causes of the NDVI anomaly.

RESULT AND DISCUSSION

NDVI anomaly map for each study area and its counterpart of true color composite images are shown in Figure 2a to 2e. Red color indicates a very low NDVI value (< 0) and is suspected as stressed vegetation area or bare ground. Green color indicates a high NDVI value (> 0.32) and is usually correlated with healthy dense vegetation area. Between those two classes area is the area with yellow color, indicating a slightly stressed vegetation.

True color composite image shows photograph using natural colors perceived by human eyes. Green to greenish color is generally vegetated area, whereas brown, reddish or yellowish color is bare ground. The man made features in this image shows sharp, straight boundary with brown, reddish or yellowish color. White color in the image is mostly cloud. Dark grey to black color in this image is associated with water body or the shadow of the cloud..

True color composite image also shows morphology of the high terrain area associated with volcanic landforms. In some prospect areas, circular features can be delineated to suggest a rim of crater or caldera. In interpreting NDVI anomaly area, all those features provide keys to support the hypothesis of high temperature thermal area. Thus, overlap between NDVI anomaly and circular features might immediately drive us to a target of high temperature thermal area.

The step by step NDVI anomaly investigation and true color composite image are described below:

1. Inspect the NDVI anomaly area, in particular the area with red color.
2. Compare the location of this anomaly with the location in the true color composite. Indicate the NDVI red anomaly that corresponds with the cloud and its shadow. This area shall not be interpreted as anomaly NDVI area. Instead it must be removed from the list of the suspected area.
3. Indicate the NDVI red anomaly area that corresponds with the location of man-made features such as city, road, rice fields etc. This area must be removed from the interpreted area.
4. Indicate the NDVI red anomaly area that correspond with the location of water body, and remove from the interpreted area.
5. After removing the NDVI red anomaly areas which are not caused by thermal process, we can be fairly certain that the remaining anomaly NDVI area is correlated with the thermal manifestation activities.
6. Use the knowledge of geothermal system conceptual model in interpreting the cause of the anomaly NDVI. Overlay of the location of previously known surface manifestation will give a great advantage.

NDVI anomaly in Ciremai Geothermal Prospect

Ciremai Geothermal Prospect is associated with an active volcano and its last eruption was in June 1938. The volcano has risen up to 3078 m above sea level. At the top of the volcano occur two craters; west and east crater with radius about 400 m and 600 m, respectively. On the southern flank, at the elevation about 2900 m above sea level, can be found a relic of the eruption called Gua Walet (Walet Cave). Geothermal manifestation occur on the crater and in some locations including G. Kromong about 20 km north of this volcano, Sangkanhurip at the eastern part, and Liang Panas about 20 km south east of the volcano (Herdianita et.al., 2010). The image in this study covers only the crater of Ciremai Volcano, while other manifestation is outside coverage area.

The NDVI map of Ciremai Geothermal Prospect and its true color composite is shown in Figure 2a. The area is largely covered by cloud (white color in TCC) in particular on the western flank of the volcano (see right figure on Figure 2a). Therefore the anomalously red NDVI area on the western flank in NDVI image (left figure) will be ignored during the analysis.

Morphology of the volcano in the TCC reflects the circular feature with midst of cloud in its center. Around this crater, an area with brownish red color apart from dark green color in TCC map can be distinguished clearly, and it is probably correspond to slightly bare ground and dense vegetated area respectively. The NDVI image gives red color exactly in this area, surrounded by yellow color. The yellow color in the NDVI image extends to the NE flank. The red and yellow anomalies are surrounded by green healthy vegetation (green).

From the above description, it is suspected that the area adjacent to circular feature is the center of crater with indication of bare ground or very limited vegetation. Gradually toward the outside of the crater, bare ground changes into heavy plants. From a point of view of geothermal energy exploration, this area need to be investigate further because it indicates strong altered ground that may associate with high temperature and low pH, which characterize an up flow zone.

NDVI anomaly in Tangkuban Perahu Geothermal Prospect

Tangkuban Perahu Geothermal prospect is associated with recent active volcano. Geothermal manifestation features show in particular warm and hot springs emerge around the foothill of this volcano. It is shown by abbreviated code letter in the TCC image (Figure 2b, right), which stand for W=warm springs, H=Hot springs, F=Fumaroles. However the most intensive manifestation is found near the crater, either in Ratu-Upas Crater or at Domas Crater. Fumaroles and Solfataras with very extensive alteration zone appear in these craters. Warm chloride springs and stream (river) occurs in Ciater area, about 2 km to the NE. Most springs have near neutral pH, except in Domas Crater and Ciater with pH values lower than 2.7 (Nasution et al., 2004).

The NDVI anomaly map and the associated true color composite is shown in Figure 2b. The image is relatively free of cloud except in the crater. In the NW area, about 2 km from the crater there is water

body, named Situ Lembang (Lembang Lake). This lake appears as red NDVI anomaly in the NDVI map, and will be ignored during the analysis.
The circular features mark the crater areas, at Domas Crater and Ratu Crater. The whole crater is surrounded by dark green color in TCC, an indication of dense vegetation. However, outside the dark green color in TCC map, there is light reddish color with rectangular shape, indicating manmade features or the city. Therefore the focus area of the analysis will be the one near the crater.

At the NDVI anomaly map, it is obvious that only the crater area show red NDVI anomaly surrounded by narrow yellow anomaly, apart from anomaly caused by water body at Situ Lembang. The morphology shows a circular feature of craters at the highest elevation of about 2084 m above sea level. NDVI anomaly in this area is caused by anomalously high temperature, suggested by the existence of fumaroles, solfataras and low pH associated with volcanic fluid. From geothermal exploration point of view, this area is suspected as up flow zone.

On the contrary, Ciater area (marked as code letter W at about 2 km NE of crater) with its water chemistry of surface manifestation suggest an occurrence of upflow, does not show any significant NDVI red features but only yellow color. It is possible that the occurrence of manmade object in Ciater has masked the result of NDVI anomaly. Furthermore, perhaps the temperature anomaly in this area is not as high as in the crater area, thus resulting a very limited vegetation stress. The stream temperature in Ciater is about 45°C while in Domas Crater is nearly boiling.

NDVI anomaly in Tampomas Geothermal Prospect

In Tampomas Geothermal Prospect, the potential heat source might be associated with Tampomas volcanic centers. The structural settings associated with E-W, NW-SE and NE-SW structures trending were also identified within the prospect area. Those structures could control the appearance of thermal manifestations in northeast down slope of G. Tampomas, particularly bicarbonate chloride hot springs indicating outflow of the geothermal system. At early stage of exploration, fumaroles were reported absent. But according to Fadillah et.al (2013), fumaroles are observed at the peak of this volcano. Therefore the occurrence of the fumaroles is still questionable. At the southern flank of the volcano, at 800 m above sea level, recently appear manifestation of hot ground that give temperature above boiling point at the surface (Dinas Pertambangan Kabupaten Sumedang, 2006;www.tempo.com, 2006).

The NDVI anomaly map and the associated true color composite are shown in Figure 2c. Cloud covers small part of NW flank of the volcano. At the peak of the volcano, subtle small circular feature can be observed, with reddish color in the TCC. Most of the flank of the volcano shows green color at TCC image indicating vegetation cover, with some patchy reddish color. The green color is surrounded by light reddish color of rectangular shape suggesting manmade features. Manifestation is mostly occurred at the foothill of the volcano to the NE. In addition, at the southern flank, an area of bare ground at the elevation <800 m above sea level is observed at TCC showing light reddish color.

The peak of volcano is covered by small area of yellow anomaly NDVI suggesting occurrence of slightly stressed vegetation. The small anomaly area and yellow color suggest that the temperature anomaly near the peak is not so high. At the southern flank the yellow NDVI anomaly adjacent with the suspected location of hot ground can be observed. The anomaly at this location gives yellow color instead of red. It is because the image used for this study is taken at 2001 before the hot ground phenomenon took placed. However indication of hot ground still can be observed apart from the appearance of bare ground. The flat area surrounding the volcano is marked by yellow color, but it is mostly caused by manmade activity. Hence the occurrence of anomaly stressed vegetation associated with the occurrence of hot springs is difficult to infer.

From geothermal exploration point of view, it might be said that if the manifestation is not so hot, fumaroles and area of manifestation is too small to be observed that may correlate with yellow or moderate NDVI anomaly; the potential may be small. The suspected area for further investigation according to this study includes the peak of volcano and the southern flank (indicated by black circle in Figure 2c). Previous study (Distamben JABAR, 2008) also mentioned a recommendation for further investigation in the area between the peak of the volcano and the occurrence of hot springs at the NE. Thus, the result of this study adds more information about prospective area determined from the previous study.

NDVI anomaly in Kamojang Geothermal Field

The production area of Kamojang Geothermal Field is situated in Pangkalan Caldera. However the intensive manifestation occurs at the NE area about

1-2 km from Pangkalan Caldera, manifested as fumaroles and hot springs.

The NDVI anomaly map and the associated true color composite are shown in Figure 2d. The Pangkalan Caldera in the TCC map is shown by reddish color suggesting a bare ground. As the consequence the NDVI image is shown mostly by yellow, indicating moderately stressed vegetation. On the contrary, most manifestation at the NE part is associated with dark green TCC color, suggesting that the manifestation is located within green vegetation. Interestingly, the area with manifestation at the NE shows yellow color of NDVI image with some patchy red color anomaly. This area can be suggested for further exploration program.

NDVI anomaly in Wayang Wndu Geothermal Field

The NDVI anomaly map and the associated true color composite is shown in Figure 2e. Most surface manifestation occurs in the area where the TCC is light reddish color with abundant rectangle suggesting manmade features. Only one manifestation is located in the green area of TCC. Circular features are also subdued. In the NDVI map the red color NDVI anomaly mostly are associated with clouds and manmade features that produce bare ground. The only red NDVI anomaly area is the area where the fumarole is situated in a green area of dense healthy vegetation. (see black circle in Figure 2.e). In such condition like in Wayang Windu area, the analysis of NDVI becomes very limited due to many ambiguities.

THE EFFECT OF GROUND RESOLUTION

Different sensor for example ASTER and Landsat ETM+ often has different ground resolution. In the visible range spectral, ASTER sensor has 15 m ground resolution, whereas Landsat ETM+ 30 m. This will reflect the detail of the image and later the accuracy of the interpretation. This is demonstrated by the following image of Tangkuban Perahu area (Figure 3). One NDVI image is generated from ASTER data and the other is from Landsat ETM+ data.

In the image generated from ASTER data, the NDVI anomaly of yellow color appear larger than in Landsat image. Red color of anomaly of vegetation stress also occur in some important place such as in Ciater, Maribaya (SE of the system) and Kancah, south of the crater.

In recent work with PERTAMINA Hulu on their exploration, NDVI anomaly map derived from ALOS AVNIR data with ground resolution 2.5 m suggests new anomaly that may correlate with the anomaly later defined by MT modeling area (PERTAMINA personal communication, 2013). This new found anomaly area is located far from the existing and known manifestation locations. It can be concluded that the size of ground resolution may contribute to the determination of anomaly NDVI area for further study.

CONCLUSIONS

Application of NDVI method in early stage of geothermal alteration is very useful. The area with low NDVI value can 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 value (red color in this study) associated with circular features, located in high elevation of a volcano is expected to be caused by high temperature, low pH, thermal activities such as fumaroles and its condensation product. These activities caused the ground to become infertile thus resulting in stressed vegetation.

The absent of circular features and high temperatures manifestation such as fumaroles, and the occurrence of manmade features made NDVI anomaly features more difficult to interpret, and to understand or infer its cause. It is suggested that while conducting analysis and interpretation of NDVI map, other information must be taken into account. This other information can be obtained from true color composite, other image or map, local knowledge consideration of geothermal system in the area, image condition such as cloud coverage and manmade features.

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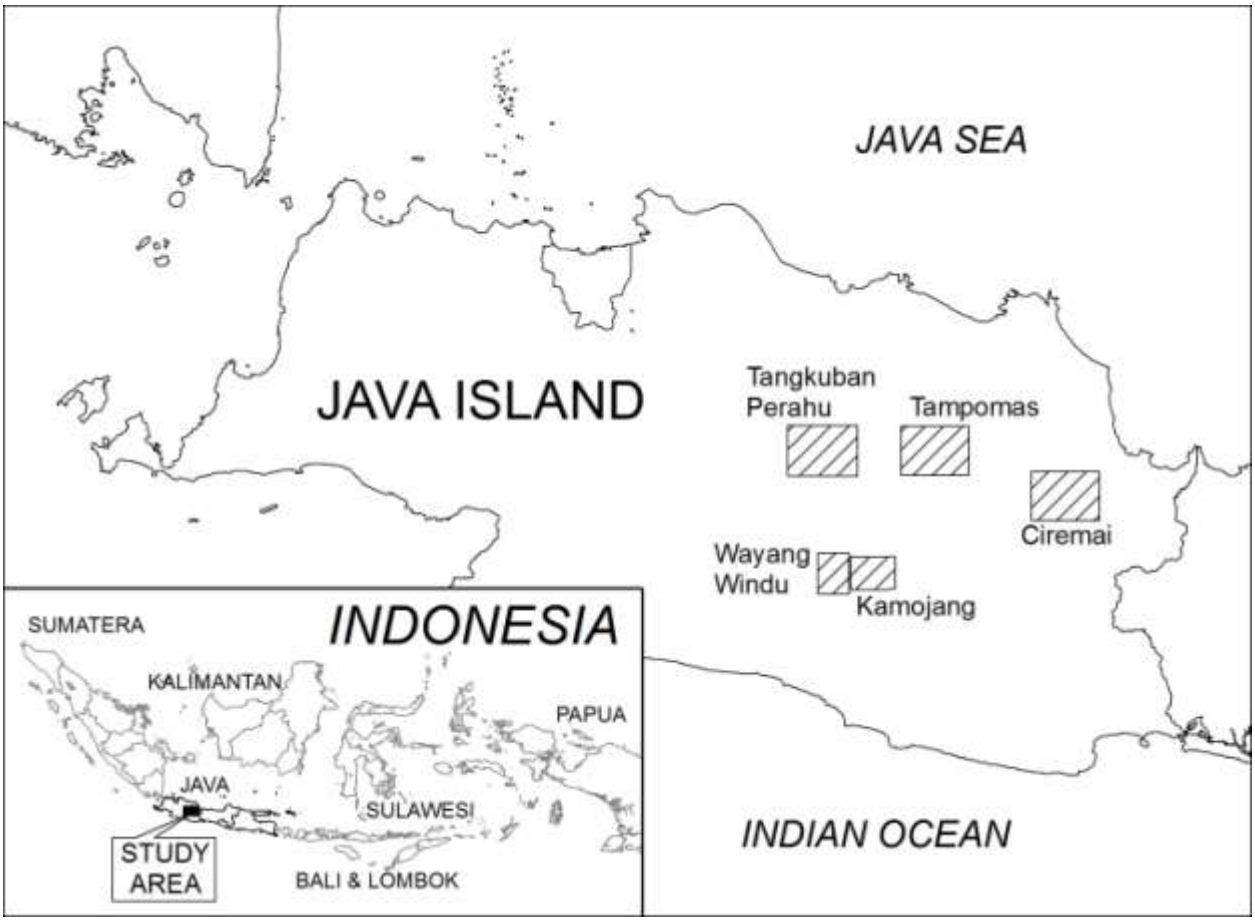

Figure 1. Study areas

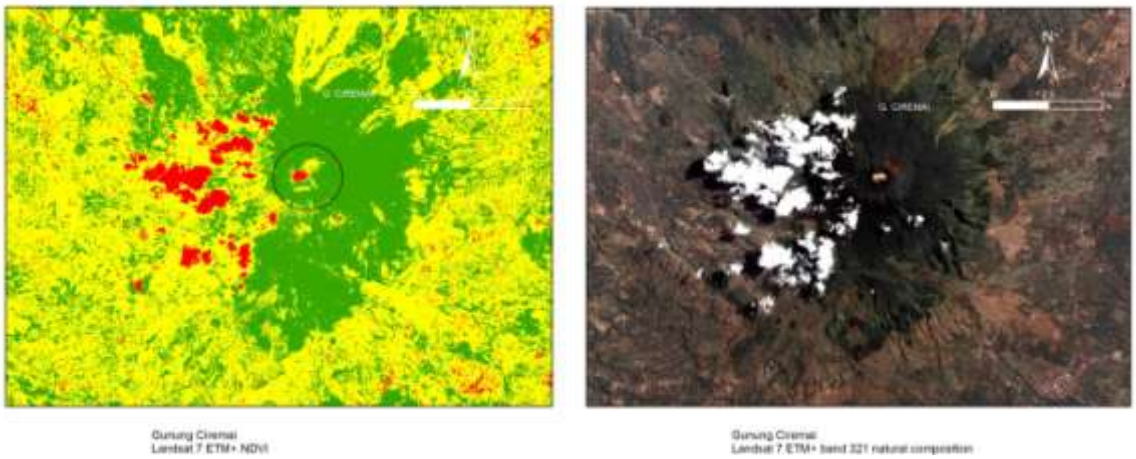

Figure 2a. NDVI map (left) and True Color Composite of Ciremai Geothermal Prospect. Black outline circle in NDVI map is suspected up flow area.

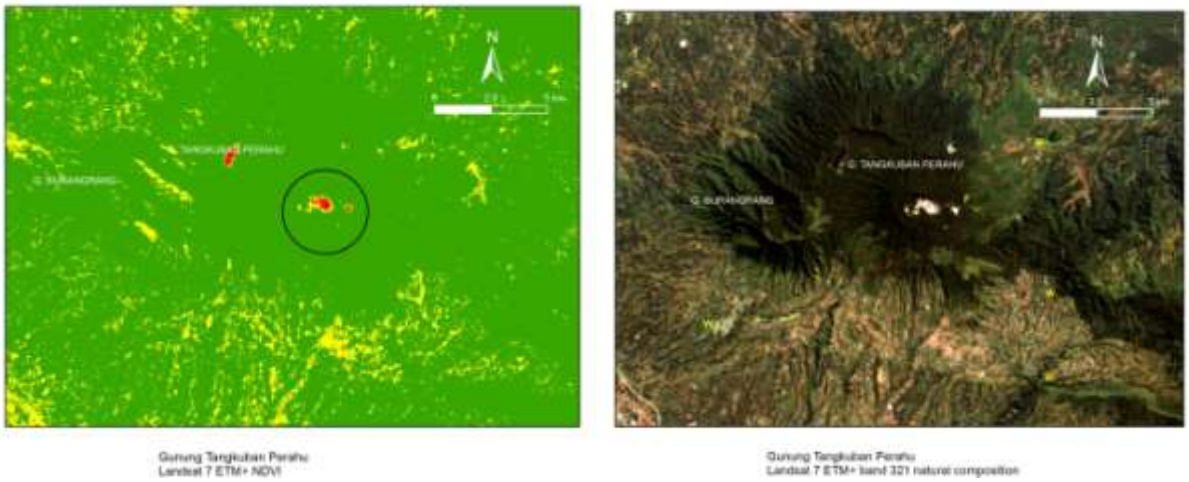

Figure 2b. NDVI map (left) and True Color Composite of Tangkuban Perahu Geothermal Prospect. Black outline circle in NDVI map is suspected up flow area. Code letter in the TCC map is manifestation (F=Fumaroles, W=warm springs).

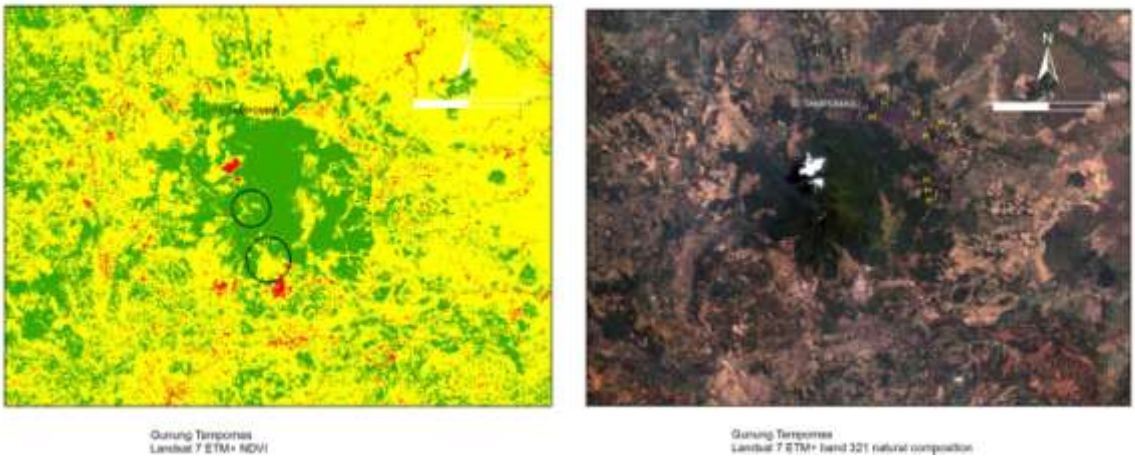

Figure 2c. NDVI map (left) and True Color Composite of Tampomas Geothermal Prospect. Black circle in NDVI map is suspected area for further investigation.

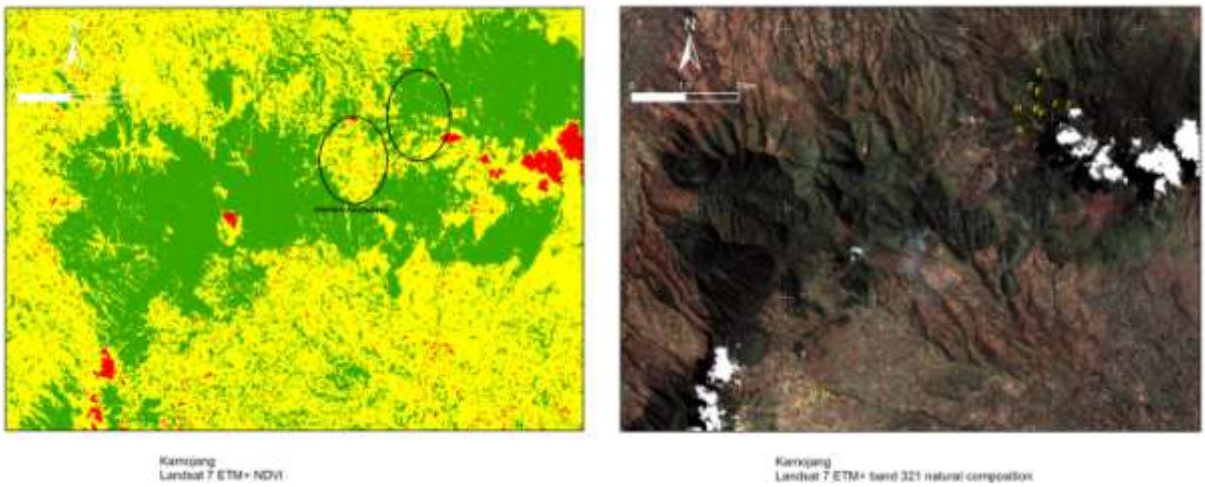

Figure 2d. NDVI map (left) and True Color Composite of Kamojang Geothermal Field. Black circle in NDVI map is suspected area is Pangkalan Caldera and area for further investigation.

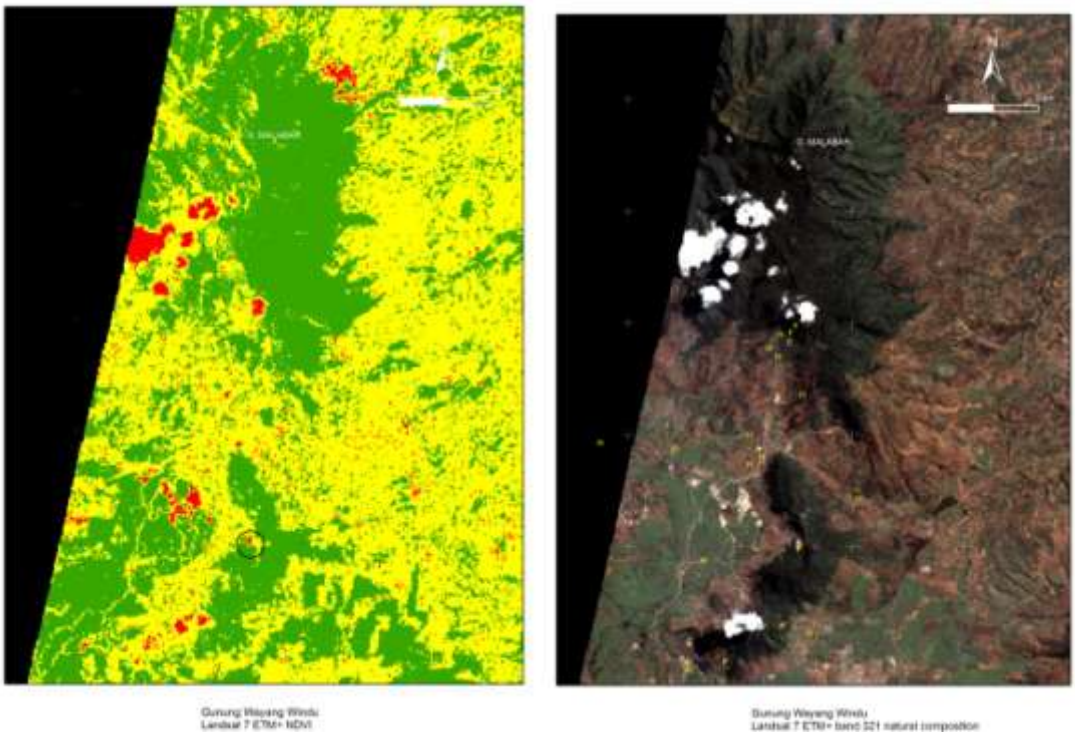

Figure 2e. NDVI map (left) and True Color Composite of Wayang Windu Geothermal Field. Black circle in NDVI map is suspected area associated with fumaroles.

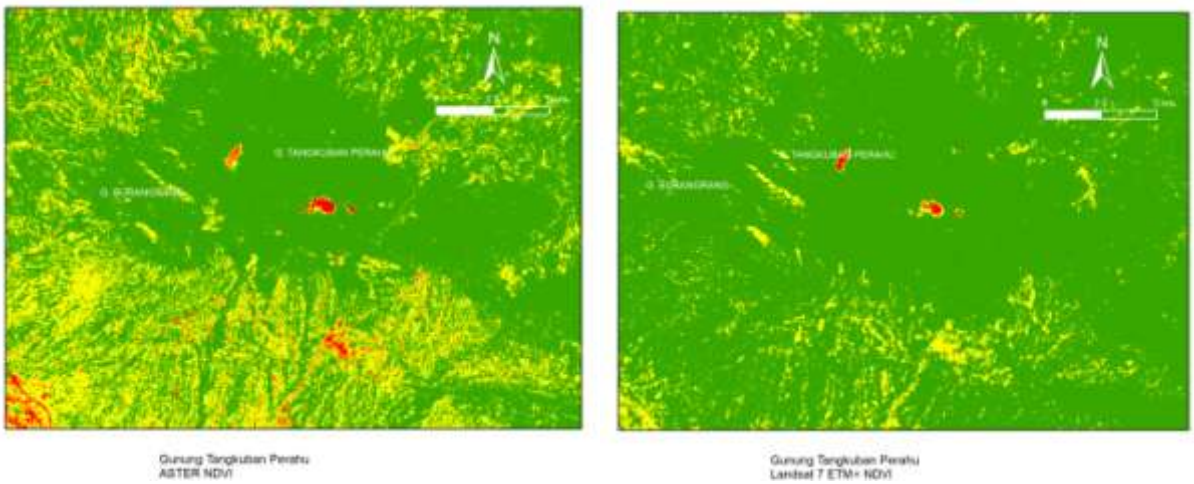

Figure 3. The effect of ground resolution on the NDVI anomaly area determination