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Vegetation Stress Analyses using Sentinel 2A Image and Field Measurement at Geothermal Surface Manifestation

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Abstract. The high-temperature geothermal areas in Java Island are located mainly within the volcanic zone extending from west to east. The demand for electrification of the areas increases, as well as the green energy utilization in Indonesia. Kamojang Geothermal Field (KGF) was selected as a study site due to the oldest geothermal field in Indonesia with high steam temperature. The analyses of vegetation indices based on remote sensing techniques at high-temperature geothermal areas have been reported by previous studies. However, comprehensive analyses with ground measurement is still limited. In this study, the normalized difference vegetation index (NDVI) was selected as an apriori indicator for vegetation stress related to the hydrothermal fluid contamination in the soil. Verifying the NDVI calculation using Sentinel 2A image, we measured the plant's physiological condition, such as chlorophyll content in their leaves, leaf dimension, and branches' length. We also measured the soil temperature at depth ±15 cm and mapped the homogeneous vegetation types (ferns). According to this study, we present the vegetation stress signature at the surface manifestation of KGF. The physiological condition of fern species, chlorophyll content, and soil temperature showed a clear negative response to the presence of geothermal surface manifestation.

Keywords: *Vegetation Stress; Geological; Kamojang, SENTINEL*

1 Introduction

Java Island in Indonesia, located in the subduction zone between the Eurasian and Australian Plate, was identified by active volcanoes with high-potential prospects of geothermal energy, especially in the south area of Java Island. The volcanic host geothermal systems in Java Island are typically a hydrothermal type that the groundwater transports and circulates in the deep crust due to heating process from the source. Through out convection process, hot fluid rises towards the ground surface, often accompanied by the deposition of rock minerals. Consequently, the environment of geothermal areas is often unique characterized by a steep gradient in soil temperature and humidity, high acidity, and high concentration of minerals (Chiarucci et al. in [1], Burns in [2], Given in [3]). These conditions affect the vegetation that can be quite different from the surroundings. Merrett and Clarkson in [4] described "geothermally" influenced terrestrial and emergent wetland vegetation as plant communities with compositional, structural or growth rate characteristics that are directly or indirectly influenced by the hydothermal fluid.

Commonly, physiological plant leaves in a large area can be identified well-using vegetation indices by botanical remote sensing techniques (Susantoro. et al. in [5]). The vegetation indices termed as VIs is an algorithm determined by band calculation of satelite images, usually on multispectral images, to highlight the vegetation condition by producing VIs images representing the vegetation phenomenon (Danoedoro in [6]). The most common used VIs is the Normalized Difference Vegetation Index (NDVI). The NDVI utilizes the physical phenomenon of reflected light from plant leaves. The greenness level of vegetation at observed area is presented by a scale from -1 to 1. The NDVI scale is calculated by comparing the reflectance of the vegetation received by the sensor in red and near-infrared wavelengths.

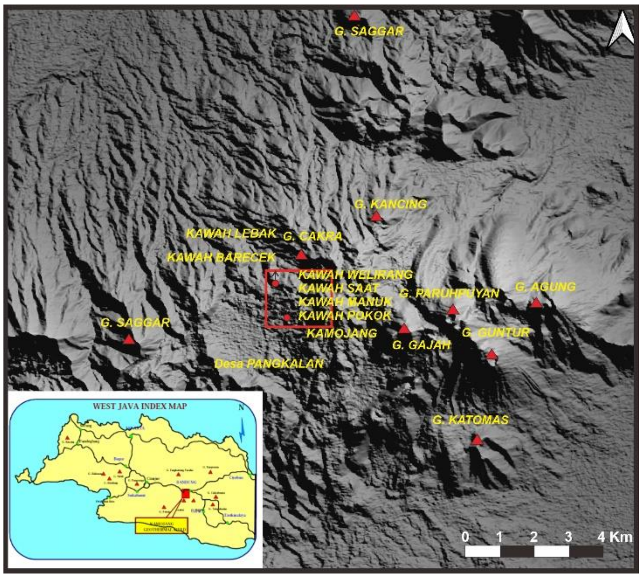

Figure 1 Study area presented by red rectangular overlaid on the shaded map of Digital Elevation Model Nasiona (DEMNAS) of Kamojang Geothermal Field (KGF).

2 Data and method

In this study, we have done a botanical remote sensing technique based on direct field measurement and VIs analysis using NDVI. The field measurement was performed to measure detail physiological plants at geothermal surface manisfestation and validate the NDVI from Sentinel 2B Level 2A.

The leaves chlorophyll content were measured using the SPAD (Soil Plant Analysis Development) tool. In addition to chlorophyll, we also collected others plant physiological data, including stem length, leaf length, leaf width, number of shoots and plant height. The soil temperatures at a depth of ±15 cm from the surface were also measured to assure the thermal contribution to the plant condition. The selected observation points were designed based on the low NDVI values and plausibility to measure in view point of safety work.

The remote sensing data used in this study consisted of two Sentinel 2B level 2A and DEMNAS (Table 1).

Table 1 Detailed data were used in this study.

No	Data type	Data ID	Acquisition
1	Sentinel 2B lv 2A	S2B_MSIL2A_20200730T024549_N0214_R132_T48MZT_20200730T065155	July 20, 2020
2	DEMNAS	DEMNAS_1308-41_v1.0	2020s

2.1 Calculating The NDVI using Sentinel 2A

The NDVI is a band calculation of the multispectral image to determine the density index of the green leaves. NDVI is a common method to estimate the greenness level of plantations. The NDVI is calculated as follows (Barbosa et al in [7]):

$$NDVI = \frac{NIR\ (Band\ 8) - RED(Band\ 4)}{NIR\ (Band\ 8) + RED(Band\ 4)} \quad (1)$$

where NIR and RED are infrared and red bands, respectively.

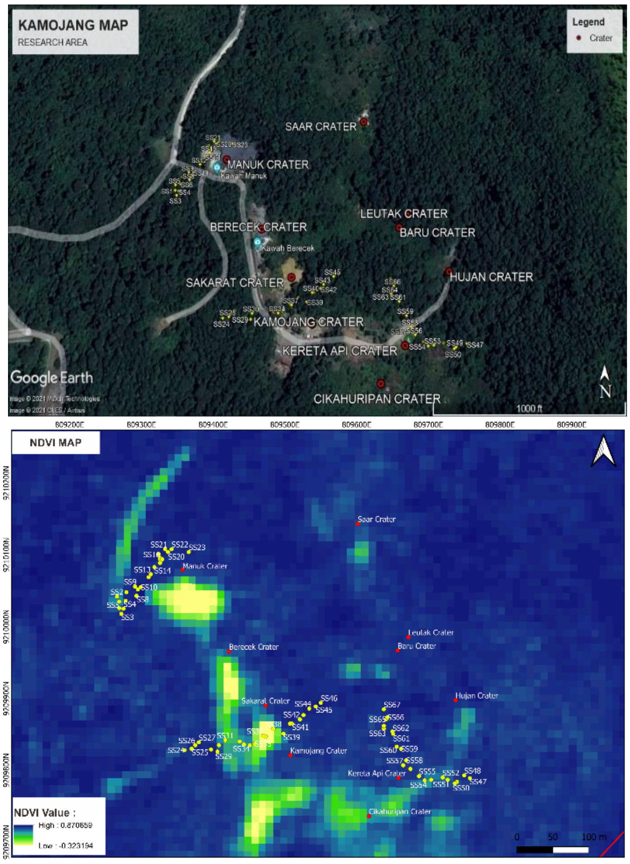

Figure 2 The Normalized Difference Vegetation Index (NDVI) Map of study. The yellow dots are field measurement points and red dots are craters points in Kamojang area.

2.2 Field surveys and measurements

Plant sampling was carried out by purposive sampling, where the target plants sought were ferns with the species of Dryopteris and Nephrolepis. Plants were collected within a radius of 10 m from each point of collection. The study was carried out by taking samples directly in the field where the ferns that were the target in this study were taken from the physical condition including stem length, leaf length, leaf width, number of shoots and plant height of the plant, chlorophyll in the leaves with SPAD measurement tools, and taking the temperature of the soil that was dug up to a depth of 15 cm first.

Figure 3 Measured fern in study area (A) normal and (B) stressed Dryopteris species, (C) normal and (D) stressed Nephrolepis species.

3 Result and discussions

3.1 Analyzing ferns chlorophyll and NDVI

Chlorophyll in plant leaves plays an important role for plants. There are three main functions of chlorophyll in the photosynthesis process: utilizing solar energy, triggering CO_2 fixation to produce carbohydrates, and providing energy (Ai and Banyo, [8]). Chlorophyll is synthesized in leaves with different role in capturing sunlight. Each plant species has its own cholorophyll level, so it can be assumed that the greater the value of chlorophyll, the more green the plant will be. The VIs value, which is the NDVI of the vegetation/canopy, is obtained from Sentinel 2B level 2A image.

In this paper, we have analyzed the performance of NDVI derived Sentinel 2A to the chlorophyll content of the Dryopteris and Nephrolepis species. Both species were selected because of their growing ability in wide-range conditions. The measurements were carried out using the SPAD tool. According to the NDVI, the minimum and maximum index value for the study area is about -0.3 and 0.8. For vegetation stress estimation, we have assigned the index about 0.1-0.4. Meanwhile, according to the data collection for chlorophyll content, we measured the range of healthy vegetation from 40 to 60 SPAD, moderate vegetation from 26 to 39 SPAD, and vegetation stress from 0 to 25 SPAD. The correlation test between NDVI and chlorophyll content shows a linear coefficient of determination R^2 about 0.63 for Nephrolepis Sp. and 0.55 for Dryopteris Sp.

(Figure 5). The data distribution shows a fairly high linear relationship from the number of data pairs as many as 40 in Nephrolepis plants and 13 in Dryopteris plants. It may indicate that the NDVI coherence parameter is quite coherent with the vegetation stress condition based on the actual plant chlorophyll content in the field.

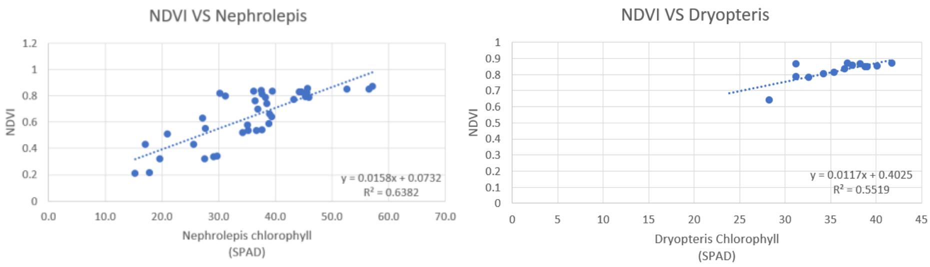

Figure 4 The correlation plot between NDVI and chlorophyll content at geothermal surface manifestations.

3.2 Estimation of ferns chlorophyll with soil temperature

In the geothermal environment at the study site, the soil temperature is in the range from 18° to 50° C. The existence of manifestations such as in Kamojang Crater affects the temperature of the surrounding soil to be higher due to the presence of thermal fluids that have high temperatures. This study determines the relationship between soil temperature and plant chlorophyll by plotting the two parameters on a graph. Parameters of chlorophyll content of Nephrolepis and Dryopteris Sp. were obtained using a SPAD tool, while soil temperature was measured using a thermocouple. The results of this study indicate that there is an inverse relationship between soil temperature and plant chlorophyll. The chlorophyll of Nephrolepis plants showed a significant decrease in soils with temperatures above 25°C, with a minimum value of 17 in plants with a soil temperature of 50°C. Meanwhile, in Dryopteris plants, no similar relationship was found due to the absence of Dryopteris plants at high soil temperature conditions.

Our study shows that soil temperature is a dominating effect on plant chlorophyll content. The high soil temperature due to thermal fluid activity affects soil moisture, soil pH, and soil chemical content, which leads to increased vegetation stress. Previous studies in geothermal areas have also shown that vegetation establishment and growth is strongly controlled by thermal gradients (van Manen & Reeves in [9]), indicating that soil temperature is the main factor responsible for a decline in root biomass and vegetation regeneration rate (Nishar et al. in[10]).

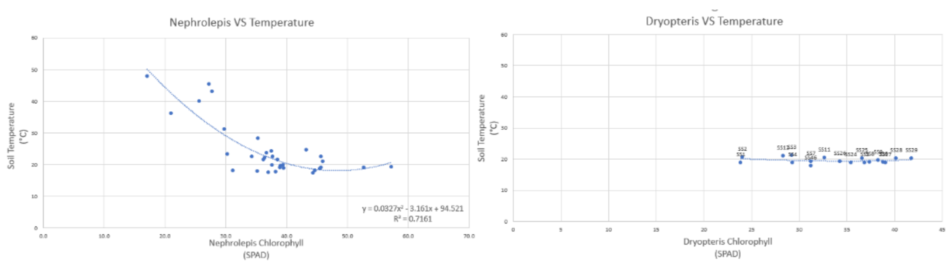

Figure 1 The correlation plot between soil temperature and chlorophyll content at geothermal surface manifestations.

4 Conclusions

According to the field measurement, we obtained that the soil temperature correlates to the chlorophyll content. The high soil temperature from the geothermal system affects soil moisture, soil pH, and soil chemical content, which leads to increased vegetation stress. The NDVI values at the geothermal surface manifestation have the minimum value for non-vegetated areas is about -0.3, and the maximum value for dense vegetation is about 0.8. The vegetation under stressed conditions is located at NDVI 0.1-0.4. According to the data collection for chlorophyll content, it is obtained that the healthy vegetation is in the range from 40 to 60 SPAD, moderate vegetation from 26 to 39 SPAD, and vegetation stress from 0 to 25 SPAD. The correlation test between NDVI and chlorophyll content was shown by the coefficient of determination R^2 about 0.63 for Nephrolepis and 0.55 for Dryopteris. Following this study, NDVI results have a high level of indicator against the vegetation's actual condition in the Kamojang area. Further investigation is needed to obtain more details about the relationship between thermal manifestation and vegetation stress

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