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Monitoring Temperature Variation in Rising Small Defunct Volcano on Jeju Island, Republic of Korea, Using High-Resolution Sentinel-2 Images

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Abstract: Global warming is not an expectation but a reality in the "oreums" (common local name for rising, small defunct volcanoes on Jeju Island, Republic of Korea). The oreums exhibit wide biodiversity. However, their ecology is threatened by its associated climate change and their ecological changes have rarely been monitored or recorded. We used three years of Sentinel-2 image data to generate a normalized difference vegetation index (NDVI) map of the Geum-oreum area. We found that the NDVI was highly associated with temperature, implying that Sentinel-2 images could be utilized to monitor the temperature variation in the oreums to assist in planning and preparation to conserve their ecosystems before they are jeopardized. The results indicated that the NDVI maps derived from Sentinel-2 images were highly associated with temperature in Geum-oreum. We expect this method could be applied in other regions to detect temperature variation for ecological management planning in large areas (such as forests).

Keywords: climate change; satellite image; global warming; forest dynamics; NDVI; Geum-oreum; Sentinel-2 image; ecological changes

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1. Introduction

Sentinel-2, a program of the European Space Agency (ESA) designed for worldwide high spatial-resolution monitoring [1], has several applications, including monitoring vegetation over a large area using the normalized difference vegetation index (NDVI) [2,3]. Recently, the NDVI obtained from Sentinel-2 images has been associated with temperature [4]. Therefore, it could be used to monitor temperature variations that cause changes in surface vegetation. The accurate and effective monitoring and analyses of small or large local, regional, or global climatic variations in time and space are important since they impact biodiversity [5].

"Oreum" is the local name for the rising, small defunct volcanoes on Jeju Island, Republic of Korea; they exhibit wide and unique biodiversity. The vascular plants of the oreums around Jeju City represent 454 taxa, 116 families, 301 genera, 359 species, 3 subspecies, 78 varieties, and 14 forms including *Cryptomeria japonica*, *Chamaecyparis obtusa*, *Pinus thunbergii*, *Styrax japonicas*, *Cornus kousa*, *Carpinus laxiflora*, *Mallotus japonicus*, *Meliosma oldhamii*, and *Acer palmatum* [6]. The Geum-oreum possesses a wide variety of subtropical trend temperate plants; its delicate but ecologically and biologically important environment is endangered by global warming. However, the monitoring of global-warming related changes in oreums have rarely been reported. Thus, we examined if the NDVI variations were associated with temperature or not. If they are correlated, NDVI could be used to monitor the temperature variations in oreums on Jeju Island and applied to other areas in response to global warming.

2. Materials and Methods

2.1. Study Area

The study area was the Geum-oreum (33°21′22″ N, 126°18′21″ E; altitude 427 m), located in Geumak-ri, Hallim-eup, Jeju-si, Jeju-do, Republic of Korea. This study used the area range provided by the quantum geographic information system (QGIS) through OpenStreetMap (Figure 1). The QGIS scope was between latitudes 3,693,824.0—3,694,154.0 and longitudes 249,174.2—249,443.6, respectively.

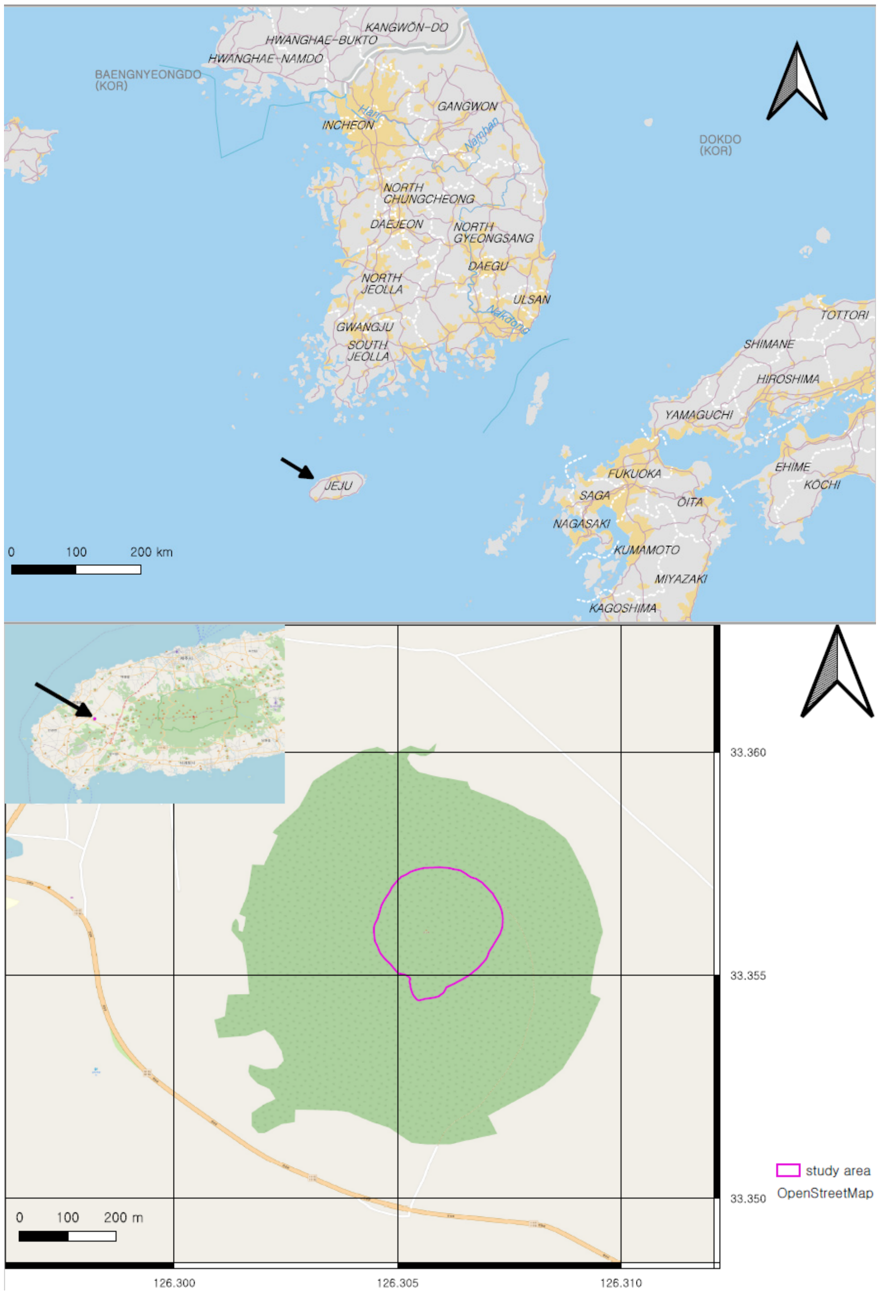

Figure 1. Map of Geum-oreum, Jeju Island, Korea. Its maximum height is about 428 m.

2.2. Data Collection

As of December 2019, 96 automated synoptic observation systems (ASOSs) were operating in the Republic of Korea, providing real-time weather and weather forecasting information. We collected meteorological data, including average, highest, and lowest temperatures, relative humidity, and total insolation at Geum-oreum from the Jeju Meteorological Agency. The daily data collected ranged from 1 May 2018, to 30 November 2021. For various reasons, 306 days were missing from the total 1310 days. The missing months were 6, 8, 9, 10 and 12 in 2018; 7, 9 and 12 in 2019; 7 in 2020; and 9 in 2021.

We collected Sentinel-2 images from the Google Earth engine and the Sentinel hub EO Browser to calculate the NDVI index of the Geum-oreum region. If the images for certain dates were not available from one of these two resources, we retrieved the data from the other. The downloaded satellite image dataset consists of an L1C image with a geometric correction only and an L2A image with geometric and radiation corrections. We could directly use the Sentinel-2 L2A data provided by the Sentinel hub EO Browser. The L1C data from the Google Earth engine were downloaded and converted into L2A data using the SEN2COR algorithm available on the Sentinel Application Platform (SNAP). We collected image data from 2 May 2018, to 28 November 2019. Since the satellites cannot image the ground surface if it is obscured by clouds, 1254 of the total 1306 days were missing. The missing months were the same as those missing from the meteorological data except for months one and two in 2020 that were unavailable from Sentinel-2 images.

2.3. NDVI Map Generation

The NDVI can be obtained using the optical index extracted from satellite images. We used band 4 (red light, RED) and band 8 (near-infrared light, NIR) from the Sentinel-2 image dataset in Equation 1 to calculate the NDVI.

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \tag{1}$$

Healthy vegetation (chlorophyll) emits more near-infrared light compared to other wavelengths. When vegetation becomes sick, the lower layer deteriorates and the chlorophyll absorbs more red light. In this regard, we are able to identify vegetation by considering the difference between the near-infrared light and the red light. The NDVI ranges from −1.0 to 1.0; it was greater than 0 in the study area. Figure 2 shows the NDVI in the Geum-oreum region from 2019 to 2021 for April. Changes in the vegetation were determined based on the NDVI.

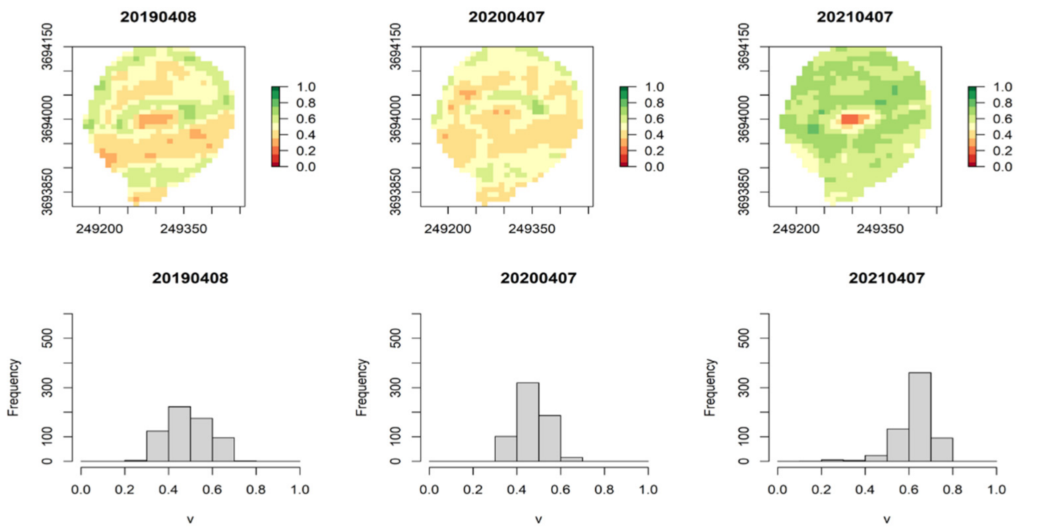

Figure 2. NDVI variation in April of 2019 to 2021 with varying temperatures.

2.4. Data Preprocessing

The NDVI data obtained using the satellite images were aligned by date with the meteorological data (temperature, humidity, and total insolation) to identify the relationships between them. We grouped the various parameters from the two datasets by month and calculated the average values. The resultant monthly data sets were for months 5, 7, and 11 in 2018; 1–6, 8, 10 and 11 in 2019; 3–6 and 8–12 in 2020; and 1–8, 10 and 11 in 2021.

2.5. Statistical Analysis

We conducted Pearson's correlation analysis to exclude highly correlated meteorological features. Figure 3 shows the correlation coefficient matrix. The Pearson correlation coefficients were all significant ($p < 0.05$). The average, lowest, and highest temperatures were highly correlated, and the average ground temperature was correlated with the average temperature. We exclude the lowest and highest temperatures and average ground temperature. The average relative humidity was highly correlated with the average temperature. We also examined the relationship of the average relative humidity to NDVI from various perspectives.

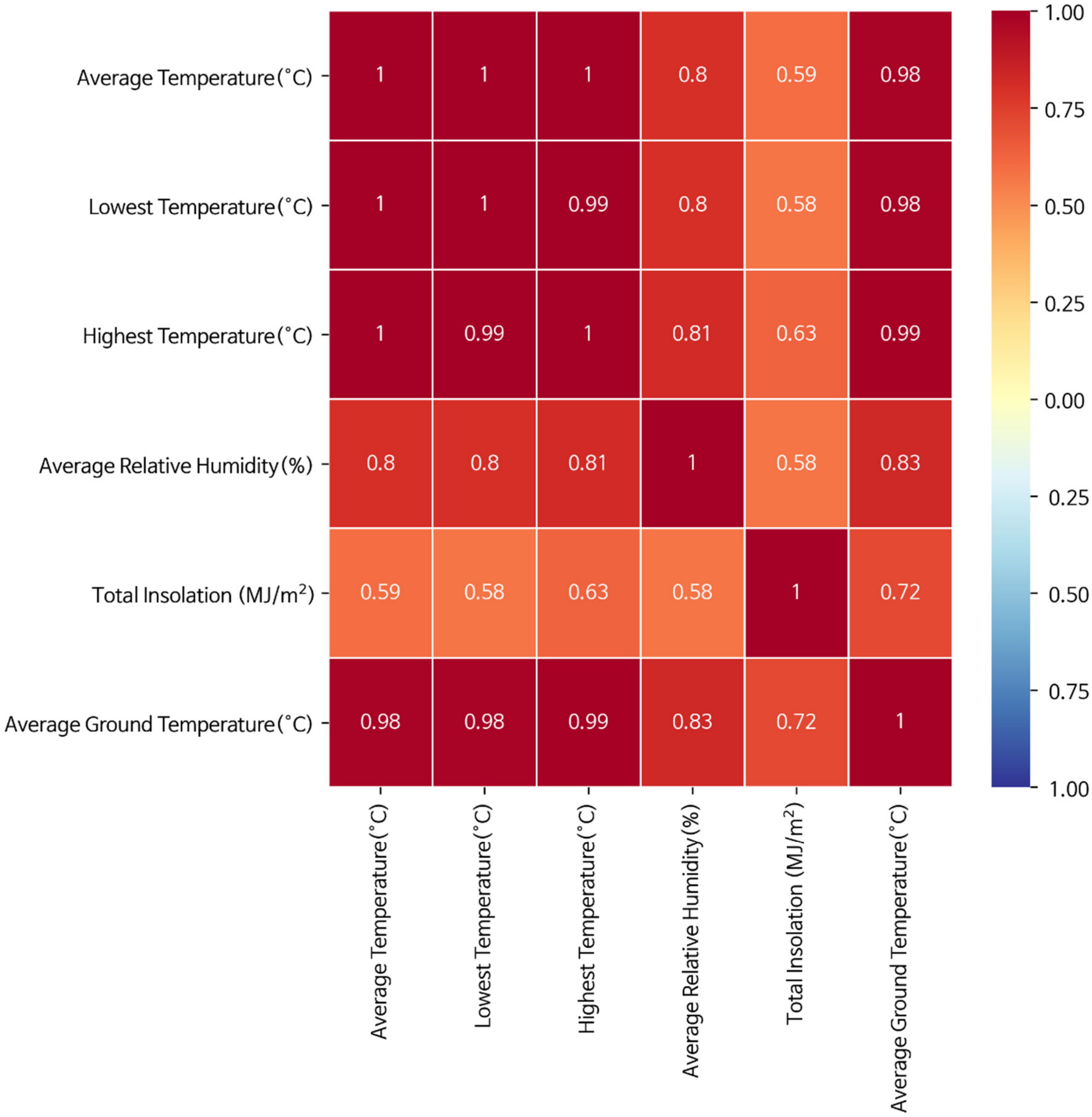

Figure 3. Pearson correlation coefficients. All values are significant ($p < 0.05$).

3. Results and Discussion

The meteorological parameters were plotted for each year and compared to the NDVI. In Figure 4, the NDVI (red line) is represented on the *y*-axis. It is shown correlated with the three meteorological features represented by green (average temperature), blue (average relative humidity), and yellow (total insolation) lines. Time is represented on the *x*-axis. Although there were missing data, we could capture the associated trend variation between the NDVI (red line) and the three meteorological parameters; therefore, we performed multivariate regression analysis to further examine the associations. We set the NDVI value as the dependent variable and the other three meteorological features as independent variables and conducted 31 observations. Table 1 shows the results of the multivariate regression analysis using the ordinary least squares method. The adjusted R-squared score was 0.908, and its *p*-value was 1.08×10^{-14}, which is less than 0.05, indicating that the results were statistically significant.

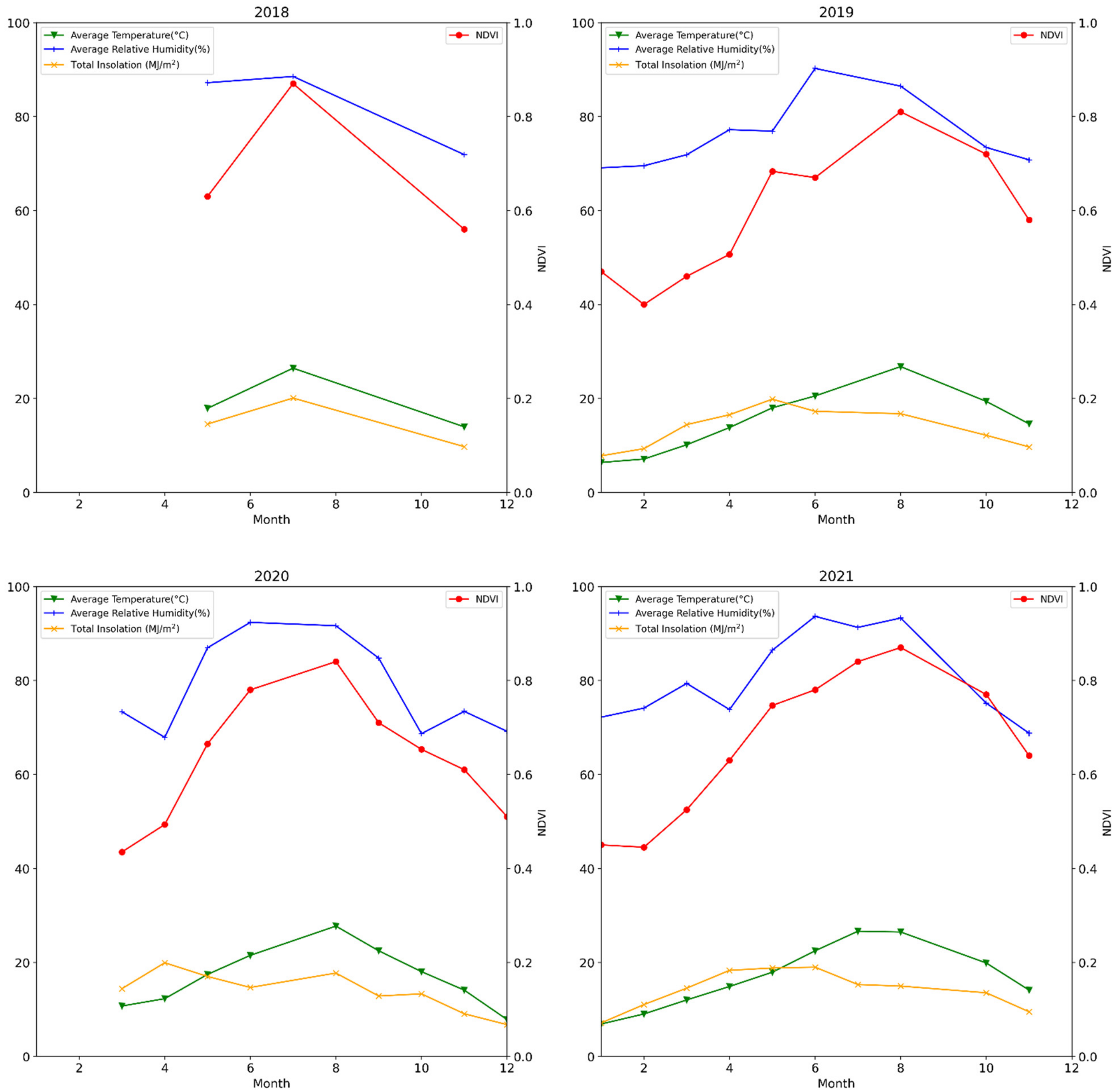

Figure 4. Graphs of Geum-oreum meteorological parameters and NDVI from 2018 to 2021. NDVI, *y*-axis; time, *x*-axis; green line, average temperature; blue line, average relative humidity; yellow line, total insolation.

Table 1. Multivariate regression.

	Coeffient	Standard Error	T	Pr (>|t|)
Constant	0.2998	0.092	3.247	0.003
Average Temperature	0.0223	0.002	10.344	0.000
Average Relative Humidity	8.98×10^{-5}	0.002	0.059	0.953
Total Insolation	−0.003	0.003	−1.199	0.241

Of the three independent variables, only the average temperature was significantly different; the *p*-values of the other two variables were > 0.05. The fitted model is shown in Figure 5. The blue line corresponds to the fitted model, and the red point represents an observation with the label (year, month). As shown in Figure 5, the NDVI can be used to predict the average temperature, and the same results with ours can be found in [7].

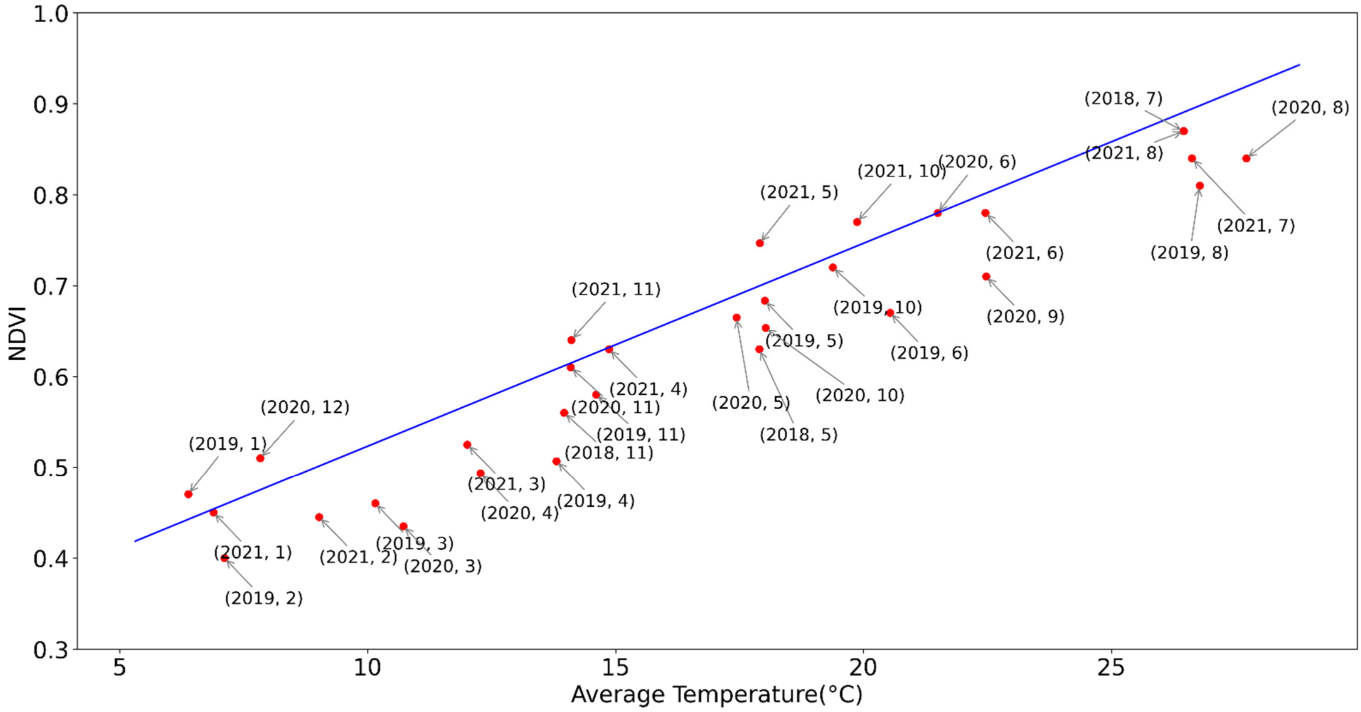

Figure 5. The chart of fitted model where the numbers in parentheses mean the year and month.

The results indicated that the NDVI maps derived from Sentinel-2 images were highly associated with temperature in Geum-oreum. Although this study was on an ideal, isotropic, small-scale forest area, it is expected that the same methodology could be applied to asymmetric complex forest areas for use in temperature monitoring and analyses.

4. Conclusions

Radical climate change can cause significant changes in biological ecosystems. Consequently, immediate and broad monitoring is essential for environmental conservation planning in valuable environments. However, high human resource and budget requirements are obstacles to research in this area. Here, we present the use of the NDVI derived from Sentinel-2 images as a tool to observe temperature variations. Since rising temperatures can alter ecosystems, temperature changes should be monitored closely. Therefore, the NDVI, as an indicator of temperature variation, would be an efficient and cost-effective tool to monitor valuable small-scale forest areas. We expect this method could also be used to detect the effects of temperature variation over large forested areas for temperature monitoring, analyses, and ecological management planning.

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Data Availability Statement: Data can be provided upon request.

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Conflicts of Interest: The authors declare no conflict of interest.

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