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Monitoring Mount Semeru's 2021 Eruption using NDVI and LST from Sentinel Satellite

Yuliana Iik Iswanti Chandra[1,2*], Sukir Maryanto[1,2], Adi Susilo[1]

[1] Department of Physics, Faculty of Mathematics and Natural Science, Brawijaya University, Jawa Timur 65145, Indonesia.
[2] Brawijaya Volcanology and Geothermal Research Center, Brawijaya University, Jawa Timur 65145, Indonesia.

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Corresponding Author:
Yuliana Iik Iswanti Chandra
yulianachandra024@gmail.com

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Abstract: Mount Semeru is an active volcano located on the island of Java. On December 4, 2021, Mount Semeru erupted again, resulting in damage and loss of life. Sentinel-2 satellite imagery was utilized for mapping vegetation areas, while Sentinel-3 was employed for assessing surface temperatures. The NDVI distribution related to the Semeru volcano eruption indicates that the extent of cloud cover, water, and open vegetation was consistent before, during, and after the eruption. Before the eruption, areas of very low vegetation were more prevalent than during and after. In contrast, areas of low vegetation were more common following the eruption compared to the eruption period and before it. Medium vegetation remained dominant after the eruption in comparison to the periods before and during it. In contrast, high vegetation was most abundant during the eruption and was at its lowest before the eruption occurred. The land surface temperature recorded before the eruption ranged from a minimum of 11.8 °C to a maximum of 30.12 °C. During the eruption, temperatures peaked at 42.4 °C and dropped to a low of 14.0 °C. Following the eruption, the maximum temperature recorded was 40.8 °C, with a minimum of 11.6 °C. The presence of lava flow during and after the eruption is indicated by the red circle on the land surface temperature map, and when compared to the NDVI map, the black circle shows areas where vegetation was absent due to the lava flow observed on the land surface temperature map.

Keywords: NDVI; LST; Semeru; Satellite Sentinel; Sentinel-2; Sentinel-3; Volcano

Introduction

Volcanoes are a type of natural disaster that requires ongoing surveillance due to their negative effects on communities (Evita et al., 2015). Various techniques can be employed for volcano observation, ranging from seismic methods to visual assessments, while long-term monitoring often integrates geophysical methods, including magnetic, gravity, and geoelectric analyses (Alwan et al., 2017; Andryana et al., 2011; Anshariyah, 2018; Antonielli et al., 2014; Hendradjaya & Hulu, 2015; Priswanto, 2019). Mount Semeru is an active volcano on the island of Java, within the Bromo Tengger Semeru National Park. It lies to the south of Mount Bromo and the Tengger mountain range, Ayeg-ayeg. From the southern viewpoint, Mount Semeru appears to have a nearly perfect conical shape, but its summit is complex due to the displacement of the crater from the northwest to the southeast. On December 4, 2021, Mount Semeru erupted once again, leading to significant destruction and loss of life. As a result, 51 individuals died, 169 were injured, and 22 went missing. Additionally, 49 public structures and 1,047 residences were severely damaged. The villages of Sumberwuluh and Sumbermujur in the Candipuro sub-district, along with Supiturang village in the Pronojiwo sub-district of Lumajang Regency, were affected. To mitigate the adverse effects on the community, efforts should have been made to predict the Semeru volcano disaster earlier(Purba et al., 2022; PVMBG, 2021; Wibowo, 2023).

The images captured by Sentinel-2 and Sentinel-3 satellites have distinct designs and purposes. The purpose of Sentinel-2 includes monitoring agricultural lands, assessing security risks, tracking vegetation, and observing coastal regions. Equipped with optical instruments, Sentinel-2 can sample 13 different wavelength bands, consisting of four bands at a 10 m resolution, six bands at a 20 m resolution, and three bands at a 60 m resolution, covering an orbital width of 290 km. In contrast, Sentinel-3 is designed to transmit optimal data at a wavelength of 1,270 km using instruments that assess ocean and land color, ensuring coverage every two days (Arafah & Aristo Tenis, 2023; Dimyati et al., 2022; Dwi Julianto et al., 2020; ESA, 2022). The goal of Sentinel-3 is to monitor the temperature, color, and height of the ocean's surface. Its innovative mission includes the capability to oversee forest fires through land use mapping and assessing the vegetation index, much like Sentinel-2; however, Sentinel-3 excels in temperature monitoring due to its design by approximately 100 companies led by Thales Alenia Space in Paris (Aisyah et al., 2021; ESA, 2022; Kandi Putri et al., 2024; Mirnayani et al., 2021a; Yang et al., 2020; Zheng et al., 2019).

(a) (b)

Figure 1. Satellite (a) Sentinel-2 (b) Sentinel-3

Figure 1 displays the silhouettes of the satellites: (a) Sentinel-1, which is employed to observe alterations in land deformation, icebergs, and other related phenomena. (b) Sentinel-3 is utilized for surveying and assessing temperature, color, and sea level (ESA, 2022).

NDVI (Normalized Difference Vegetation Index) is a metric that indicates the degree of greenness in plants, representing a mathematical interplay between the red band and the NIR (Near-Infrared Radiation) band, which has historically served as a measure of vegetation presence and health (Pahlevi & Firdaus, 2022).

In essence, the assessment of NDVI indicates that healthy vegetation absorbs radiation efficiently in the photosynthetically active radiation (PAR) spectrum, leading to a strong reflection of near-infrared radiation by green plants. The value of this index can be calculated using equation 2.1, which is presented below:

$$\text{NDVI}=\frac{\text{NIR}-\text{Red}}{\text{NIR}+\text{Red}} \quad (1)$$

Explanation:
NIR: Near-infrared radiation from the pixel
Red: Radiation of red light from the pixel
The NDVI value ranges from -1 (usually water) to +1 (dense vegetation).
(ESA, 2022)

Table 1. NDVI Value Description (Feriansyah et al., 2020)

NDVI value	Plant Description
-1 NDVI -0.03	Cloud cover, water, open vegetation
-0.03 NDVI 0.15	Extremely Low Vegetation
0.15 NDVI 0.25	Low Vegetation
0.25 NDVI 0.35	Medium Vegetation
0.35 NDVI 1	High Vegetation

Land surface temperature refers to the average temperature of a surface represented in pixel units across different types of surfaces. The SLTR LST is an official Level-2 product with a spatial resolution of 1 km, which provides estimates of LST along with several related parameters. The SLTR data product on Sentinel-3 has three processing levels (Level-0, Level-1, and Level-2), with Level-1 and Level-2 accessible to the public. Level-1 products present calibrated radiance and brightness temperature (RBT) for each channel within the instrument network, available for both nadir and oblique views, along with additional information. Level-2 products include measurements for sea surface temperature (SST), land surface temperature (LST), and fire radiative power (ESA, 2022).

Based on the thermal radiation transfer model, in a cloudless atmosphere at local thermodynamic equilibrium, the radiation detected at the top of the atmosphere (TOA) can be represented as:

$$\text{LST} = (a_0 + b_0 T_{11} + c_0 T_{12}) - 273.15 \quad (2)$$

Explanation:
a_0, b_0, c_0 = the coefficient class applied to brightness temperature (BT) that depends on water vapor in the atmosphere, satellite viewing angle, and land surface emissivity.
T_{11}, T_{12} = Brightness Temperature (BT) on T_{11} and T_{12} (ESA, 2022)

This research intends to explore the relationship between Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) across the periods preceding, during, and following the eruption of Mount Semeru on December 4, 2021. Furthermore, it will include an analysis of the patterns in land surface temperature derived from LST processing and an evaluation of the variability in NDVI distribution.

Method

NDVI (Normalized Difference Vegetation Index) processing procedure utilizing data from Sentinel-2 L1C. Gather Sentinel-2 images that include band 4 (RED) and band 8 (NIR). 2. Apply radiometric correction to address variations in sensor response to different lighting conditions during data capture using QGIS software. 3. Trim the image as required using the extraction clip by layer plugin with the supplied shapefile. 4. The trimmed image is analyzed using the raster calculator feature in QGIS software. 5. The final step in processing the Sentinel-2 image can be converted into a vegetation density index map in the map layout within QGIS software. 6. To identify the categorized area, utilize reclassify by table and r.report in the QGIS software.

Method for processing Land Surface Temperature (LST) using data from Sentinel-3 (SLTR). Prepare Sentinel-3 images utilizing sea and land surface temperature radiometer (SLTR) data. 2. Conduct radiometric correction to address variations in the sensor's response to different light conditions during data collection. 3. Following image correction in the SNAP toolbox, export the image from SAFE format (Science Archive Format for Europe) to Tagged Image File (TIF) format for compatibility with QGIS software. 4. Utilize the extraction clip by layer plugin to crop the image as necessary with the provided shapefile. 5. Process the cropped image using the raster calculator in QGIS with a conversion of -273.15 to achieve the intended unit °C. 6. The processed image can then be used to create a land surface temperature map in the QGIS software's map layout.

The process of data processing in the research can be seen in the research diagram as follows (Figure 2).

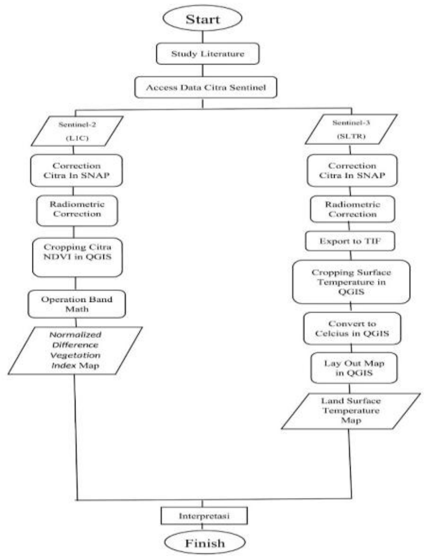

Figure 2. Flow chart research

Result and Discussion

Normalized Difference Vegetation Index using satellite sentinel-2. Before the eruption of Mount Semeru.

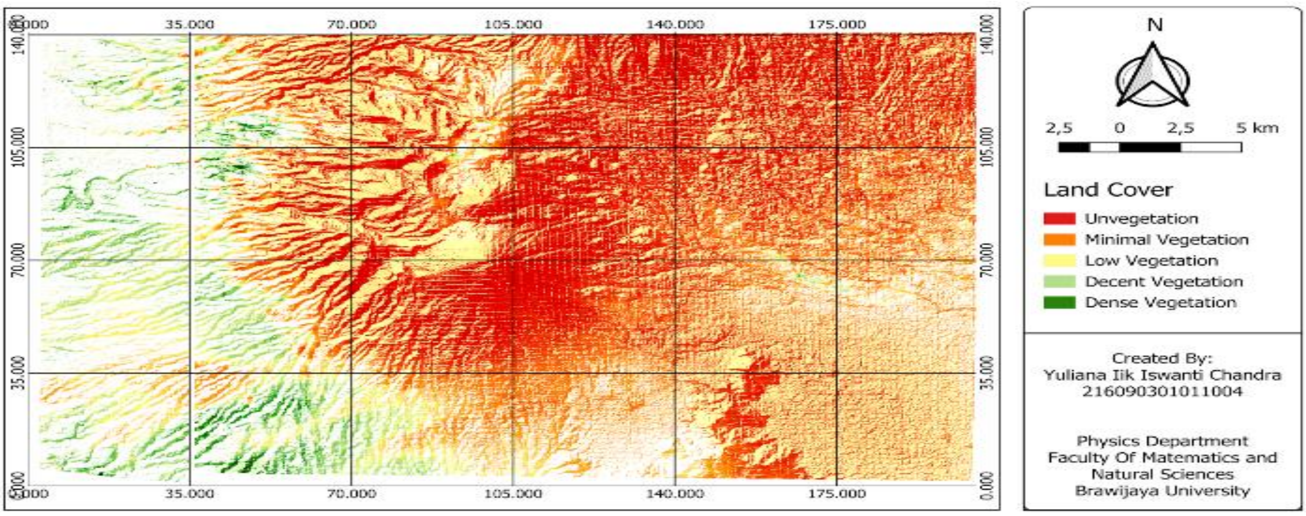

Figure 3. NDVI map before the eruption of Mount Semeru in 2021

Table 2. NDVI area before the Semeru volcano eruption in 2021

Density	NDVI value	Wide (km)	Percentage (%)
Cloud Cover, Water, Open Vegetation	-1 NDVI -0.03	35.22390	3.41
Extremely Low Vegetation	-0.03 NDVI 0.15	719.7292	69.65
Low Vegetation	0.15 NDVI 0.25	120.90020	11.70
Medium Vegetation	0.25 NDVI 0.35	113.08990	10.94
High Vegetation	0.35 NDVI 1	44.44520	4.3

Before the eruption of Mount Semeru in 2021, the NDVI indicated the spread of NDVI extent in Table 1, revealing that there were 35.22390 km of regions occupied by clouds, water, and open vegetation, as illustrated in Figure 3. The entire Mount Semeru structure faces the northeast, east, and southeast directions. Very low vegetation, measuring 719.7292 km, is oriented towards the east, southeast, south, and slightly towards the southwest of Mount Semeru. Low vegetation covers 120.90020 km and is found in the south, southwest, west, and northwest areas. Moderate vegetation, totaling 113.08990 km, is distributed across the south, southwest, west, and northwest regions. High vegetation, amounting to 44.44520 km, is present in the south, southwest, west, and northwest areas.

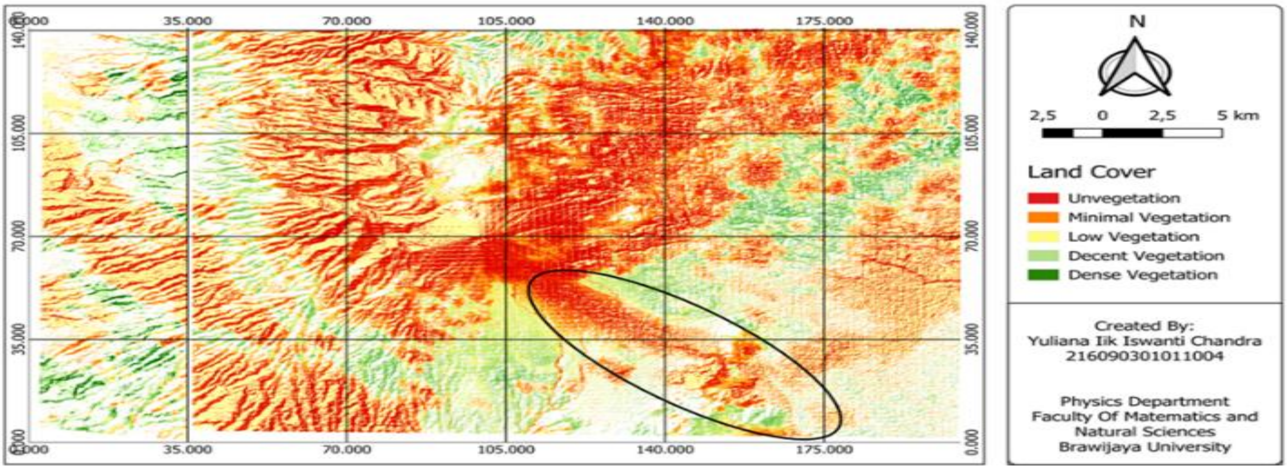

Figure 4. NDVI map during the eruption of Mount Semeru in 2021

Table 3. NDVI area during the 2021 Semeru volcano eruption

Density	NDVI value	Wide (km)	Percentage (%)
Cloud Cover, Water, Open Vegetation	-1 NDVI -0.03	35.22390	3.40
Extremely Low Vegetation	-0.03 NDVI 0.15	568.3206	55
Low Vegetation	0.15 NDVI 0.25	136.16610	13.18
Medium Vegetation	0.25 NDVI 0.35	132.81410	12.85
High Vegetation	0.35 NDVI 1	160.86370	15.57
		1033.3884	100

The NDVI data collected during the 2021 eruption of Mount Semeru illustrates the extent of NDVI, as presented in Table 2. Prior to the eruption, there were 35.22390 km of area characterized by clouds, water, and open vegetation, as depicted in Figure 4, which spread out in all directions. Very low vegetation occupied an area of 568.3206 km primarily towards the east and southeast of Mount Semeru, while low vegetation spanned 136.16610 km, distributed in all directions, with the majority found in the southeast. Moderate vegetation covered 132.81410 km, also scattered throughout the cardinal directions, and high vegetation encompassed 160.86370 km, distributed in all directions, although only a limited amount was located in the northeast, north, and northwest.

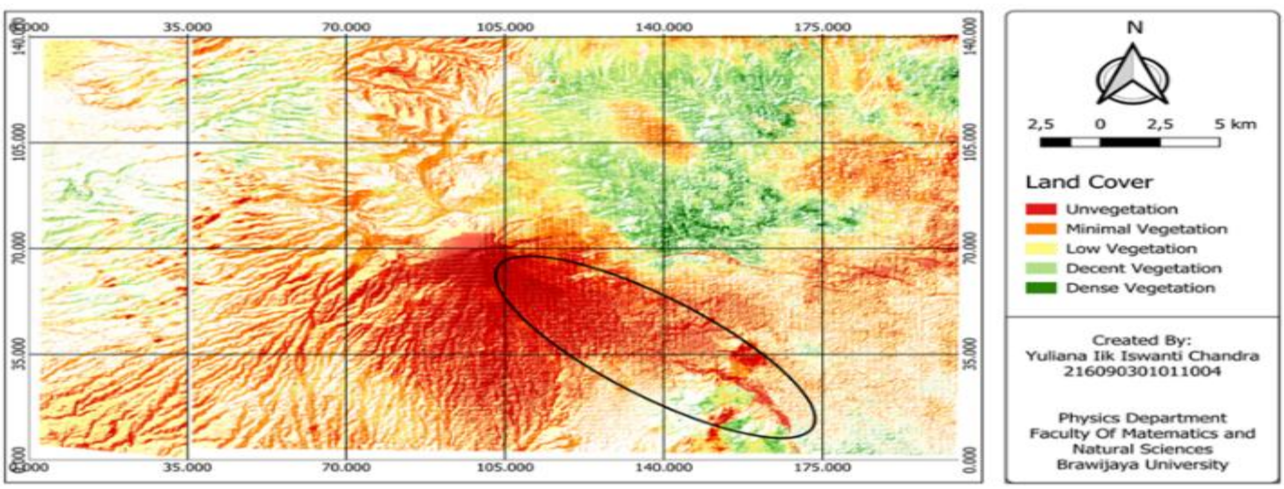

Figure 5. NDVI map after the eruption of Mount Semeru in 2021

Table 4. NDVI area after the eruption of Mount Semeru in 2021

Density	NDVI value	Wide (km)	Percentage (%)
Cloud Cover, Water, Open Vegetation	-1 NDVI -0.03	35.2252	3.41
Extremely Low Vegetation	-0.03 NDVI 0.15	259.86840	25.15
Low Vegetation	0.15 NDVI 0.25	389.82550	37.72
Medium Vegetation	0.25 NDVI 0.35	236.66420	22.90
High Vegetation	0,35 NDVI 1	111.8051	10.82
		1033.3884	100

The NDVI analysis following the eruption of Mount Semeru in 2021 illustrates the distribution of NDVI areas in table 5.3. Prior to the eruption, there were 35.2252 km of regions occupied by clouds, water, and open vegetation, as depicted in figure 5.9, which extended throughout the entire southeastern, southern, and southwestern sections of Mount Semeru. Very low vegetation, spanning 259.86840 km, is found in all cardinal directions, with the highest concentration located in the west, southwest, south, southeast, and east. Low vegetation, covering 389.82550 km, is distributed in the southwest, west, northwest, north, northeast, east, and southeast directions, with the greatest prevalence in the southwest, west, northwest, and north zones. Moderate vegetation, encompassing 236.66420 km, is also found in the southwest, west, northwest, north, northeast, east, and southeast directions, with the highest concentrations noted in the north, northeast, and east areas. High vegetation, which covers 111.8051 km, is concentrated in the northeast, east, and to a lesser extent in the southeast.

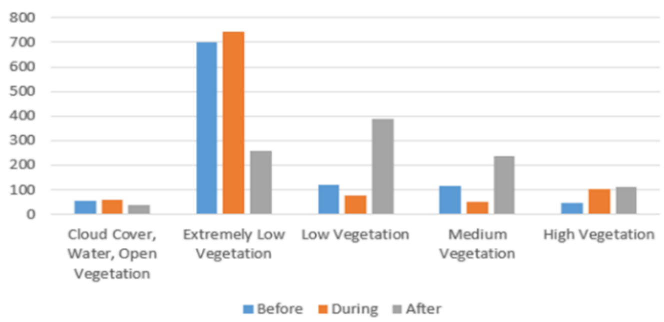

Figure 6. NDVI distribution map of the Semeru volcano eruption in 2021

The NDVI analysis of the Semeru volcano eruption in 2021, depicted in Figure 5.10, reveals that the NDVI distribution graph for the eruption illustrates that the land cover and NDVI cloud cover remained consistent at 3.4%. Prior to the eruption, very low vegetation occupied the largest area at 69.65%, while during the event it decreased to 55%, and following the eruption, it further dropped to 25.15%. Low vegetation occupied the most significant area after the eruption at 37.72%, with 13.18% during the eruption and 11.70% before the eruption. Medium vegetation accounted for the largest area after the eruption at 22.90%, with 12.85% during the event and 10.94% beforehand. High vegetation reached its peak area during the eruption at 15.57%, decreasing to 10.82% after the eruption and standing at 4.3% prior to the eruption.

The analyzed Sentinel-3 satellite imagery data reveals variations in land surface temperature that took place in 2021, specifically: prior to the eruption, during the eruption, and following the eruption.

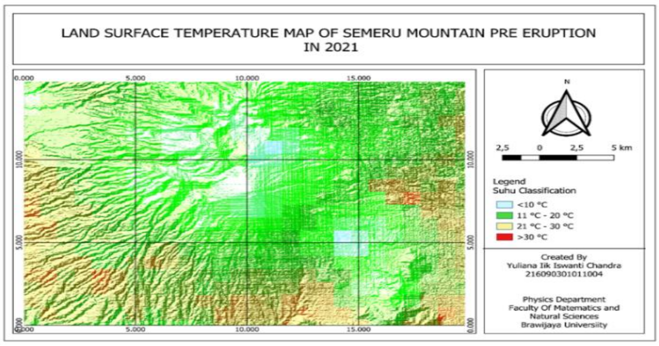

Figure 7. Map of land surface temperature before the 2021 eruption

Figure.7 presents the map prior to the 2021 eruption of Mount Semeru. The minimum temperature recorded before the eruption was 2.64°C, represented in light blue, indicating a temperature below 10°C due to cloud cover at the summit of Mount Semeru. The green areas on the map prior to the eruption reflected a temperature of 11.8°C, signifying that vegetation almost entirely covered Mount Semeru. The maximum temperature before the eruption reached 30.12°C, indicated by the color red, which denotes a temperature above 30°C, permitting land use or similar activities.

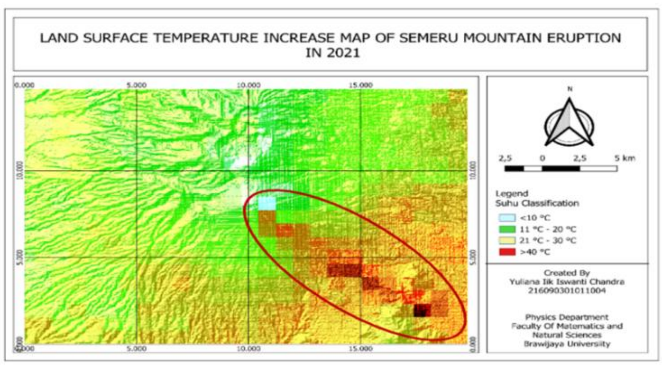

Figure 8. land surface temperature map during the 2021 eruption

The processed map displayed in Figure 8 illustrates the activity during the 2021 eruption of Mount Semeru. The lowest recorded temperature during this eruption was below 10°C, suggesting that a cloud cover surrounded the peak of Semeru. A temperature of 14.0°C, highlighted in green, represents nearly the entire area of Mount Semeru. The maximum temperature observed during the eruption reached 42.4°C, which is indicated by the red color on the map. The eruption map depicts the lava flow starting from the summit of Semeru, moving through the openings created by earlier eruptions.

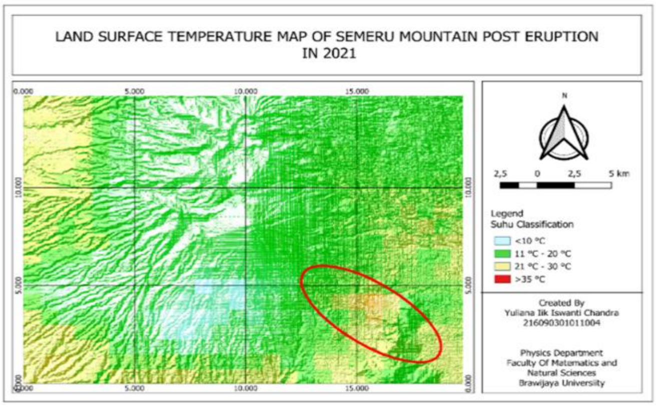

Figure 9. land surface temperature map after the 2021 eruption

A map following Mount Semeru's 2021 eruption is shown in Figure 9. Because of the cloud cover in the southern section of Mount Semeru, the lowest temperature on the map following the eruption is less than 10°C. Nearly the whole Semeru mountain was covered in green, indicating a temperature of 11.6°C. Additionally, the red tint of the eruption's lava flow indicated that the maximum temperature following the eruption was 40.8°C.

Conclusion

The area of research spans 1033.3884 km² and includes data collected before, during, and after the eruption of the Semeru volcano in 2021. The distribution of NDVI related to the Semeru volcano eruption indicates that cloud cover, water, and areas of open vegetation remained consistent in extent before, during, and after the eruption. Very low vegetation was more widespread prior to the eruption than during and after it, while low vegetation was more prevalent following the eruption compared to the periods before and during it. Medium vegetation continued to be more significant after the eruption in comparison to before and during, and high vegetation was most prominent during the eruption, being at its lowest level beforehand. The land surface temperature recorded before the eruption showed a minimum of 11.8 °C and a maximum of 30.12 °C. During the eruption, temperatures peaked at 42.4 °C with a minimum of 14.0 °C. After the eruption, the highest recorded temperature was 40.8 °C, and the lowest was 11.6 °C. The red circle depicted on the land surface temperature map denotes the presence of lava flow during and after the eruption, whereas, on the NDVI map, the black circle signifies the lack of vegetation due to the lava flow shown on the LST map.

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Author Contributions
Author contributions include Sukir Maryanto and Adi Susilo: focusing on methodology, reviewing, etc.; Yuliana Iik Iswanti Chandra: collecting data, processing data, analyzing data, and writing the original manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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