Spatiotemporal analysis land surface temperature in relation to earthquake occurrence around the cimandiri fault

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Abstract. Cimandiri Fault is one of the faults that have high tectonic activity. Several earthquake events around the Cimandiri Fault have caused impacts and losses on humans. Efforts to detect earthquake events need to be done as disaster mitigation. Detection of earthquake events in this study by looking at deviations in surface temperature. This study was conducted to investigate the relationship between changes in land surface temperature (LST) in relation to the earthquake that occurred on 7 July 2018 (M_L = 4.73) and 11 October 2018 (M_L = 3.77). Landsat 8 satellite imagery are used in this study to get the value of the land surface temperature using the LST algorithm. To find out the deviation that occurred researchers used a statistical test x ± σ with a 66% confidence level and compared with the average LST for five years. The results of the study are an increase in land surface temperature due to the earthquake occurrence on July 7, 2011, an increase in surface temperature of land was 6.56°C on the day before the earthquake, and October 11, 2011, there was an increase of 7.02°C the day before the earthquake.

1. Introduction

Indonesia is an archipelago state located at the boundary of three major tectonic plates, the Indo-Australian, Pacific, and Eurasian plate which stretches from Sumatra to West Papua [1]. As a result of the meeting of the three plates, making Indonesia an area that has high tectonic activity such as plate movements [2]. This high plate movement activity forms a series of volcanoes (ring of fire) that stretches from Sumatra, Java, Bali, Lombok, Sumba, and Flores which are formed through the process of subduction [3]. The existence of the volcano series has caused Indonesia to become one of the places that have high volcanic and seismic activities, thus causing Indonesia as an archipelago state which has high disaster hazards such as earthquakes, volcanic eruptions, tsunamis, landslides, and ground movements [4].

The geological conditions in the western part of Indonesia there are subduction zones formed by subduction between the Indo-Australian plate and the Eurasian plate with movements around an average of 50 to 70 cm per year [5]. The movement of the two plates triggers movement in faults on the island of Java, one of which is the Cimandiri Fault which is located in the southern mountains of Java which stretches from Sukabumi to Padalarang [6]. Thus, the collision between the Indo-Australian plate and the Eurasian plate is responsible for high seismic activity and earthquakes in the Cimandiri fault area.
Several major earthquakes around the Cimandiri fault were recorded and had a great impact on humans, including the Pelabuhanratu earthquake (1900), the Cibadak earthquake (1973), the Gandasoli earthquake (1982), the Padalarang earthquake (1991), the Tanjungsari earthquake (1972), the Conggeang earthquake (1948), and the Sukabumi District earthquake (2011) [7]. The Cimandiri fault zone consists of six segments that are close to several cities including Pelabuhanratu, Sukabumi, and Padalarang. Earthquakes that occur around cities will be more dangerous because they have the potential to cause damage to a number of buildings and cause more deaths [8].

Based on the explanation, earthquake prediction has an important role in the process of disaster mitigation. Thus, earthquake prediction is a contentious issue among earth scientists and its success is highly anticipated. Earthquake prediction research has provided an understanding of the mechanism of earthquake sources, fault zone complexity, earthquake event intervals, and determination of earthquake hazard locations [9]. In recent years, research on earthquake prediction has turned into research on the emergence of earthquake precursors [9]. One method that has been developed is monitoring land surface temperature before and after an earthquake, especially related to monitoring land surface temperature anomaly before the earthquake event through remote sensing techniques using satellite imagery [10].

Based on research conducted by Tronin, explaining some special characteristics that appear before an earthquake, including anomalous land surface temperatures usually appear 4-20 days before the earthquake event, variations that appear quite significant 3-10°C, and have decreased after earthquake events [11]. Anomalous land surface temperature monitoring activities can be carried out through thermal behavior analysis using the land surface temperature algorithm obtained from satellite imagery [10]. Remote sensing satellites such as NOAA-AVHRR, Aqua-MODIS, Terra-MODIS, Meteosat-5, Landsat-5, Landsat-7 and Landsat-8 can measure radiation coming from the earth through thermal sensors so that it can be used in studies on land surface temperature anomalies [12]. Research on earthquake precursors in Indonesia by observing changes in land surface temperature through remote sensing is still limited. Therefore, this research was conducted to determine the relationship between land surface temperature anomalies and earthquake events.

2. The Study Area

The research area was carried out around the Cimandiri fault located in Sukabumi Regency, West Java Province. In this study conducted around the Cimandiri fault which is an active fault with the appearance of several manifestations of hot water as a companion [13]. The research area can be seen in Figure 1. Meanwhile, the selection of the research area is based on the physical characteristics that exist in the region including the main fault of the Cimandiri fault, the local fault, and there are several hot springs. The characteristics of areas that have sensitive locations such as active fault lines and hot springs are said to be effective regions in detecting ground surface temperature anomalies [14][15].

Figure 1. Research Area
3. Method

The method used to obtain land surface temperature values is obtained from Landsat 8 images from USGS using the land surface temperature algorithm. Landsat 8 satellite carried two sensors: the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The OLI sensor has nine bands with 30 m spatial resolution, while the TIRS has two thermal bands (TIR 1 and TIR 2) with 100 m spatial resolution with the temporal resolution of this remote sensing system is 16 days [16]. Meanwhile, band 4 (red wavelength, 0.64-0.67 µm), band 5 (near-infrared (NIR) wavelength, 0.85-0.88 µm), and band 10 (thermal infrared sensor (TIRS) wavelength, 10.60-11.19 µm) are used to obtain LST value. A flowchart of the used algorithm is shown in Figure 2.

4. Result and Discussion

4.1 Spatiotemporal Thermal Anomaly related to Earthquake in Cimandiri Fault 2018

The phenomenon of leaking gases or the release of greenhouse gases such as CO₂, H₂, Rn, Ne, He, SO₂, and H₂O which moves up due to the increased pressure accumulation results in an increase in surface temperature before an earthquake occurs. These gases rise through fissures or rupture, then the gases and steam absorbs short-wave radiation and causes warming of land surfaces [19] In addition to the phenomenon of gas leaking, the process of concentrating stress and friction concentrations in the area in the hypocenter area that triggers an earthquake requires a large amount of energy, then this energy is converted to heat and spread convectively to the earth’s surface. This process also contributes to the
increase in temperature at the earth’s surface [19] Case study of earthquake events in this research is on July 7, 2018, with a magnitude of 4.73 with a depth of 10 km accompanied by aftershocks on July 15 with a magnitude of 47.2 with the same depth, and July 11, 2018, with a magnitude of 3.77, and July 17, 2011, with a magnitude of 5.38 and a depth of 57.7 km.

It can be seen in the graph that LST in July and September exceeds the threshold value of the thermal anomaly threshold (Figure 3). An increase in ground surface temperature trends in relation to the 7 July 2018 earthquake event with a magnitude of 4.72 an increase in the land surface temperature of 6.56 °C on the day before the earthquake. Furthermore, the earthquake on October 11, 2018, with a magnitude of 3.77 there was an increase of 7.02 °C the day before the earthquake.

Figure 3. Temporal Variation Land Surface Temperature 2018

The results of data processing show the difference in the land surface temperature of the land between monthly LST with an average of five years LST (2013-2017). The highest LST difference occurred in July and October which can be seen in Table 2. On the day before the July 17, 2018 earthquake had a difference of 6.56 °C with a magnitude of 4.72 earthquakes. Meanwhile, one day before the 11 October 2018 earthquake had a difference of 7.02 °C with an earthquake of magnitude 3.77. The increase in land surface temperature before the earthquake was in accordance with research conducted by Tronin which stated that the land surface temperature of the ground would rise before the earthquake [11].

Table 1. Thermal Anomaly Threshold Value

| Bulan                              | May     | June | July     | August | September | October |
|------------------------------------|---------|------|----------|--------|-----------|---------|
| 5 Year LST Average (°C)            | 21.46   | 21.33| 19.94    | 23.15  | 24.50     | 19.77   |
| Monthly LST 2018 (°C)             | 24.20   | 24.23| 25.38    | 23.26  | 28.50     | 26.80   |
| x (mean LST 2018)                 | 21.76   | 21.76| 21.76    | 21.76  | 21.76     | 21.76   |
| x + σ (Threshold of an anomaly) (°C) | 25.00   | 25.00| 25.00    | 25.00  | 25.00     | 25.00   |
| x – σ (Threshold of an anomaly) (°C) | 18.24   | 18.24| 18.24    | 18.24  | 18.24     | 18.24   |

Source: Data Processing, 2019
Table 2. Time of Precursor Anomaly in Land Surface Temperature before Earthquake Event

| Month   | Monthly LST (°C) | 5 Year LST Average (°C) | The Difference in LST (°C) | Precursor Time (Days) |
|---------|------------------|-------------------------|---------------------------|-----------------------|
| May     | 24.2             | 21.46                   | 2.74                      | -45                   |
| June    | 24.23            | 21.33                   | 2.90                      | -27                   |
| July    | 26.5             | 19.94                   | 6.56                      | -1                    |
| August  | 23.26            | 23.15                   | 0.11                      | 7                     |
| September | 28.5           | 24.91                   | 3.58                      | -16                   |
| October | 26.8             | 19.77                   | 7.02                      | -1                    |

Source: Data Processing, 2019

Changes in land surface temperature before and after the earthquake event was spatially analyzed using Landsat 8 imagery data. The earthquake that took place on July 7, 2018, with a magnitude of 4.73 shows that there has been an increase in land surface temperature that is very spreading, especially in the main fault zone of the Cimandiri fault, and accompanying local faults the day before the earthquake with the highest temperature of 36.3 °C.

Then, 7 days after the earthquake the earth’s surface temperature decreased to the highest temperature of 31°C (Figure 4.a). In the second case study, the changes in surface temperature that occurred with the magnitude 3.77 earthquake on 11 October 2018 showed a different pattern because a very significant increase in temperature occurred 16 days before the earthquake with the highest temperature of 39.6 °C. Meanwhile, the highest temperature on the day before the earthquake was 37.4 °C (Figure 4.b).

4.2 Fault, Epicenter, and Rock Types Related to Earthquake

The phenomenon of land surface temperature anomalies in this study was associated with a variable distance from the fault, the distance from the epicenter, and rock types. Monitoring of land surface temperature anomalies is most effective when done in the fault zone [1]. The findings in this study that the distance from the fault and the distance from the epicenter have a close relationship with changes in land surface temperature at each sample point with each correlation value and the coefficient of determination are 0.86 (R² = 0.75) and 0.69 (R² = 0.69).
Meanwhile, based on the regression test found no relationship between rock types with changes in soil surface temperature because it has a low correlation and coefficient of determination value of 0.03 ($R^2 = 0.01$). Based on the buffer analysis in this study, it was found that the spatial pattern was closer to the fault and epicenter, the tendency was the greater the value of changes in land surface temperature, and vice versa the farther away from the fault and epicenter the smaller the value of the change in surface temperature.

5. Conclusion
In this study, Landsat 8 can be used to detect thermal anomalies as earthquake precursors. In this research, the LST algorithm is used to extract the surface temperature values from Landsat 8 imagery and to use statistical processing to decide the occurrence of anomalous land surface temperatures before an earthquake. The results showed in two earthquake case studies around the Cimandiri Fault that there was a significant increase of 6.56°C the day before the earthquake on July 7, 2018 ($M_L = 4.73$) and 7.02°C the day before the October 11, 2018 earthquake ($M_L = 3.77$). However, this research has a disadvantage that is located on the Landsat temporal resolution and this study does not involve meteorological variables. Suggestions for future research can use images that have a higher temporal resolution.

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