Analysis of the Relationship between Forest Fire and Land Surface Temperature using Landsat 8 OLI/TIRS Imagery

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Abstract. Forest fires are the main threat to the sustainability of forests around the world destroying the valuable forest biodiversity and nearby infrastructure. Forest covers provide shading, cooling the environment, and lower thermal absorption. However, the changes in forest cover due to forest fires increase the land surface temperature (LST) locally. This study is aimed to analyze the relationship between forest fires and LST using Landsat-8 OLI/TIRS imagery in Kuala Baram, Sarawak. More than 1500ha of forests and plantations have been destroyed after 26 days of fires, deteriorating the air quality to hazardous levels, damaging the nearby house and infrastructure. The differenced normalized burn ratio (dNBR) between pre-fire and post-fire NBR was used to estimate the burn severity categories in Kuala Baram, Sarawak. It was found that the burn severity ranges from moderate-low to moderate-high levels. The correlation between forest fire and LST in Kuala Baram, Sarawak in June 2019 and September 2019 was calculated using Pearson's correlation coefficients. It indicates the strongest negative relationship between NBR and LST in pre-fires ($R^2=-0.985$) and post-fires ($R^2=-0.996$). The findings from this study showed that forest fires also affecting the land surface temperature of Kuala Baram, Sarawak along with the physical damages that have been diminished from the forest fires occurrences.

1. Introduction

Forests play a crucial role in mitigating climate change and providing the basic needs to the animals and human well-being. However, human activities and natural disasters contributing to forest fires have led to the degradation of the forest environment. Forest fires have both positive and negative effects on forest health and the effects vary significantly according to the forest type, climate and duration of the fires [1].

Forest fires occur due to direct or indirect activities. Open burning for land clearing and human negligence during activities at the forest area are the example of direct causes while the meteorological factors are indirect causes of forest fires. The main parameters related to forest fire are dryness and moisture, wind, precipitation and humidity [2].

Land surface temperature (LST) is also one of the most important factors causing the forest fire. Fire-induced environmental changes resulted in the spatial variation of LST, primarily due to reduced transpiration. Previous study has shown that the lower LST values were recorded at the post-fire burned
area as compared to during the forest fire occurrences. However, the study shows the recorded values were higher than the pre-fire event. Therefore, burn severity identified as the amount of change in a burned area in terms of pre-fire conditions for the current study is highly dependent on the magnitude of the fire and can be considered a key variable in understanding the spatial distribution of LST in the forest fire [3]. Remote sensing has the capability to map forest fires over large areas temporally, allowing rangers to see much larger surfaces than from the ground. Remote sensing data acquired in the thermal infrared region is an attractive alternative for the detection of fires. It can provide a continuous record of temperature changes [4].

2. Study area
The selected study area is at Kuala Baram, Sarawak as shown in Figure 1. Kuala Baram is near Miri, Sarawak, Malaysia. It is a long stretch of the Baram River and a flowing floor of Ulu Baram. The position area of Kuala Baram located 04°34'36" N, 113°59'13" E. This study area was selected because forest fire often occurs in Sarawak. The cases of forest fire in Kuala Baram occurred in August 2019. In this study, these areas covered 18 286 ha area of Kuala Baram, Sarawak.

![Figure 1. Location of the study area.](image)

3. Methodology
This study consists of four main steps which is data collection, data processing, data analysis and map production as shown in Figure 2. This study used Landsat 8 OLI/ TIRS. The dataset were processed using Erdas Imagine 2013 and ArcGIS software.
3.1 Normalized Burn Ratio (NBR) derivation
The Normalized Burn Ratio (NBR) index is commonly used to identify the burnt area. This method uses a near-infrared (NIR) or short-wave (SWIR) component of the electromagnetic spectrum [5] as shown in equation 1.1. In this study, differenced NBR (dNBR) was also used to differentiate the changes in severity level within fire perimeters. dNBR is acquired by subtracting the indices of normalised burned intensity before and after a forest fire as shown in equation 1.2 [6]. There are five levels of burn intensity which are unburned (UB) (-0.1 to +0.1), low severity (LS) (0.1 to 0.27), moderate-low severity (MLS) (0.27 to 0.44), moderate-high severity (MHS) (0.44 to 0.66) and strong (HS) (>0.66) [3].

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NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)} \quad (1)
\]

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dNBR = NBR_{pre-fire} - NBR_{post-fire} \quad (2)
\]

3.2 Land Surface Temperature (LST) derivation
Land Surface Temperature (LST) is the temperature of the surface, which cannot be observed directly. There are many algorithms to calculate Land surface temperature. These algorithms include Split-Window algorithm (SW), Dual Angle (DA) and Single-Channel algorithm (SC) [7]. In this study, the split-window measurement was used to measured LST from Landsat 8 imageries. According to [1], split-window algorithm can combine brightness temperature derived from band 10 and band 11. However, following the instruction by USGS on January 6, 2014, TIRS band 11 is not using due to its larger calibration unreliability.

3.3 Correlation Indices
In this study, Pearson correlation statistic, or also known as the linear correlation coefficient, is used to assess the strength and direction of the linear relationship between forest fire and LST. Coefficient values vary between -1 and +1[8].

Figure 2. Overall methodology.
4. Results and analysis

4.1. Analysis of NBR

In this study, the Normalized Burn Ratio (NBR) index is used to identify the burnt area. The results of pre-fire and post-fire NBR are shown in Figure 3. The bright white part indicates that the area was unburned while the dark forest areas indicate a high burn.

![Figure 3. Pre-fire NBR (a) and post-fire NBR (b) images.](image)

4.1.1. The changes between pre-fire NBR area and post-fire NBR area. Based on Table 1, five classes of NBR refer to high burn area, moderate-high burn area, moderate-low burn area, the low burn area and unburned area. The first class indicates high burn areas are increase by 3.31% followed by the second class and third class show the moderate-high burn area and moderate-low burn area where an increase by 2.25% and 1.68% respectively. On the other hand, the fourth class indicates a low burn area has been decreased by 0.04%. Last, the fifth class shows the unburned area showed a higher decrease in the changes by 7.2%.

| NBR class | Class Names | Pre-fire NBR area | Post-fire NBR area | Difference (ha) | Change (%) |
|-----------|-------------|-------------------|--------------------|----------------|------------|
| 1         | High burn   | 1124              | 1730               | 606            | 3.31       |
| 2         | Moderate-high burn | 1887          | 2296               | 409            | 2.25       |
| 3         | Moderate-low burn | 1996           | 2305               | 309            | 1.68       |
| 4         | Low burn    | 3506              | 3498               | -8             | -0.04      |
| 5         | Unburned    | 9773              | 8457               | -1316          | -7.2       |
|           | Total       | 18 286            | 18 286             | -1316          | -7.2       |

4.2. Analysis of dNBR

dNBR is the spectral index applied to evaluate the severity level from the forest fires occurrences in Kuala Baram. Table 2 shows the area statistics of burn severity in seven classes. Each class indicates its burn severity category. 81.20% of the Kuala Baram area is categorized as unburned category (class 1). The area that considered as moderate-low severity is 5.82%. Low severity and low post-fire regrowth represented 4.58% and 4.16% of burn severity area, 2.15% of moderate-high severity and 2.09% of high post-fire regrowth. There was no area involved in the high severity category. Based on Table 2, the area of unburned category indicates unaffected area from fire while the area of moderate-low severity burns category and low severity burn category show more severity damage in this study.
Table 2. Area statistics of burn severity in Kuala Baram.

| Class                        | Burn severity categories       | Area (ha) | Percentage (%) |
|------------------------------|--------------------------------|-----------|----------------|
| 1                            | High post-fire regrowth        | 382       | 2.09           |
| 2                            | Low post-fire regrowth         | 760       | 4.16           |
| 3                            | Unburned                      | 14848     | 81.20          |
| 4                            | Low Severity                   | 838       | 4.58           |
| 5                            | Moderate-low Severity          | 1065      | 5.82           |
| 6                            | Moderate-high Severity         | 393       | 2.15           |
| 7                            | High Severity                  | 0         | 0              |

4.3. Analysis of LST
In this study, the land surface temperature is used to identify temperature values in the forest fire area in Kuala Baram. The maximum of LST value derived from Landsat TIR for pre-fire event is 31.2°C while the maximum of LST value for post-fire event is 36.7°C. It was observed that the highest temperature exists in the built-up areas and no vegetation cover due to the forest fire. In contrast, the lowest temperature exists in the vegetation area.

4.4. Relationship between Forest Fire and Land Surface Temperature.
The correlation coefficient test was performed. The relationship between the forest fire and the land surface temperature has been widely accepted. The correlation coefficients of Karl Pearson between two variables were determined using the Minitab 16 statistical software. Pearson's correlation coefficient was used to determine the correlations on each pixel for June and September 2019.

Figure 4. The correlation between NBR and LST.

Figure 4 shows the correlation between NBR and LST distribution expressed by the value of the Pearson correlation. The result of Pearson correlation between pre-fire NBR values with pre-fire LST value is -0.985 while post-fire NBR value with post-fire LST value is -0.996. This result shows that the direction of the relationship between NBR and LST has a negative correlation. The scatter plot for Pre-fire is shown in black colour and the scatter plot for post-fire shows in red colour. Post-fire is moderately higher than that of the pre-fire. The higher the NBR value, the lower temperature and where the lower NBR value, the higher temperature. The higher NBR value indicates unburned forests. The lower NBR value in pre-fire indicates a built-up area while the post-fire indicates the effect of forest fire due to the burnt forest areas.
4.5. Forest Fire map
In this study, the map of burned areas and fire severity be assessed by the Normalized Burn Ratio (NBR). The NBR is generally calculated as a satellite image before and after a forest fire. In this study, before forest fire occurred on June 18, 2019, while after forest fire on September 22, 2019.

4.5.1. Normalized Burn Ratio (NBR) map. Details of the pre-fire and post-fire forest conditions can be seen in figure 5 and figure 6. The red colour represents the burning forest, and the green colour represents unburned forests.

The higher NBR value indicates unburned areas, while lower value indicates bare ground and burnt areas. The burning forest area indicates low reflectance in the near-infrared and high reflectance in the shortwave infrared band. In contrast, the unburned area shows high near-infrared reflectance and low reflectance in the shortwave infrared portion of the spectrum.

Figure 5. Pre-fire NBR map. Figure 6. Post-fire NBR map.

4.5.2. Differenced Normalized Burn Ratio (dNBR) map. In this study, dNBR was the spectral index applied for burn severity evaluation due to the very strong association observed. The map in figure 7 shows the differenced Normalized Burn Ratio (ΔNBR) for June 16 and September 22, 2019, in Kuala Baram. dNBR was classified into seven different classes.

High post-fire regrowth, low post-fire regrowth, unburned, low-severity burn, moderate-low severity burn, moderate-high severity burn, and high-severity burn. The dark green area represents high post-fire regrowth category, and the red represents high severity burn category. In figure 7, the area of moderate-low severity burns category and moderate-high severity burn category shows more severity damage while the area of unburned category indicates vegetation productivity. The forest fire area in this study shows a moderate severity burn.
5. Conclusions
This study shows Landsat imageries have the potential in analysing the relationship between forest fire and land surface temperature. NBR and dNBR indices were used to analyse burn intensity and severity level while LST were derived using the split-window algorithm. The relationship between the forest fires was calculated using Pearson's correlation coefficient.

This study has been successfully identifying the burnt area in Kuala Baram, Sarawak with 2.15% of Kuala Baram area in moderate-high severity category and 5.82% in the moderate-low severity category. The finding also showed strong negative relationship between LST and NBR value. It indicates that, the unburned areas have low surface temperature while the forest areas that affected from fires have high temperature. It can be concluded that forest fires also affecting the land surface temperature of Kuala Baram, Sarawak along with the physical damages that have been diminished from the forest fires occurrences.

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