Characteristics of forest and land fires in Baluran National Park, Situbondo Regency, East Java

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Abstract. Fire events of Baluran National Park occurred periodically in the dry season. The impacts of the fires was a changes in physical, chemical and biological aspects of the ecosystem that can be illustrated as the fire severity. Important information for habitat management, is vegetation and air temperature as biological and physical aspects. This study aims to identify burned areas and classes of fire severity and to explain the character of fires based vegetation’s aspects and air temperature during the fire periods. The character of the fires was described by analysis of normalized burn ratio (NBR), normalized difference vegetation index (NDVI), and the calculation of air temperature under conditions prefires, postfires, and the delta’s value. Burned areas in Baluran National Park were identified as 1798.92 ha which classified into fire severity class as low class (1252.71 ha), medium class (543.79 ha), and severe class (2.43 ha). Savanna has a value of dNDVI of 0.2543 which is caused by logging acacia wood for firewood and dNBR of 0.0677 that indicated by burning by the local people for grass growth as livestock’s feed. Changes in the air temperature of the savanna of 8.6 °C. Increasing of air temperature is followed by decreasing of vegetation index (dNDVI an dNBR), but changes in air temperature tend to follow the dNBR’s trend rather than the dNDVI’s trend.

1. Introduction

Baluran National Park (TN) is one of the conservation areas available with a quite complete diversity of ecosystems. The function of several ecosystems such as savannas in Baluran National Park provide the availability of feed for several types of herbivores. However, in the past two years land fires had often occurred in Baluran National Park. The distribution of hotspots that have been mapped by Sutomo [20] shows that there were approximately 390 hotspots between 2000 and 2013 in the Baluran National Park. Scattered hotspots can be illustrated as indicator of fire in Baluran National Park. Fire events in 2018 were recorded in the May-November range which included the dry season. The intensity of forest and land fires are quite massive and occured periodically in Baluran National Park. It has an impact on changes in a number of aspects such as physical, chemical, and biological aspects. Then, it can be illustrated as fire severity, especially this study focuses fire severity based on burned area.

The effect of fires can prevent the growth of woody plant seeds, such as Acacia nilotica which is invasive in Baluran National Park. So, This causes the grass vegetation to be free from the influence of
the shade from the canopy cover and undergrowth vegetation competition [19]. Fire intensity has a clear effect on the initial succession of undergrowth vegetation in the burned area and clearly has a long-term impact on the understorey vegetation composition [20], [28]. Deliberate fire events cause land to be less favored by grazing animals than land which grows back after burning period [2]. Land and forest fires also affect changes in regional land cover that is always dynamic. Changing land cover to non-forest cover causes differences in air temperature. Some biodiversity is threatened with extinction due to an increase in the earth’s temperature by an average of 1°C. Each individual must adapt to the changes that occurred, while their habitats will be degraded [13]. The impact of rising temperatures on wildlife is affecting growth, life cycle, reproduction rate, survival, and distribution, especially on insect taxa which is one of the feeds of birds [6]. High and low temperatures can result in low survival of house flies (Musca domestica) [9].

Information of land fires in Baluran National Park has been carried out only a limited number of times regarding fire zoning and the direction of fire spread [21], [22]. However, there are not many studies that assess the impact of fire in the form of the relationship between aspects of vegetation (vegetation index) and biological and physical aspects (air temperature) in Baluran National Park.

2. Methods

2.1. Data type

This research was conducted from March 4 to March 18 2019. Data collection was located in Baluran National Park, East Java, while data processing and analysis were located at the Environmental Analysis and Spatial Modeling Laboratory, Department of Forest Resources and Ecotourism Conservation, Faculty of Forestry, Bogor Agricultural University. This research used primary data to answer the research objectives and secondary data to support primary data processing. Primary data consists of Landsat 8 OLI TIRS (path / row: 117/65) with the time of prefire acquisition (30/4/2018), postfire acquisition (07/10/2018), and the existing image (01/04/2019) through downloading on the USGS earth explorer website. Primary data processing were layerstack, geometric correction, radiometric correction, and image cutting based on Baluran National Park administration and from the cloud. The formula in radiometric correction is as below:

\[ L_{\lambda} = \left( \frac{L_{\lambda}^{\max(i)} - L_{\lambda}^{\min(i)}}{QCal_{\lambda}^{\max} - QCal_{\lambda}^{\min}} \right) x (QCal - QCal_{\min}^{\lambda}) + L_{\lambda}^{\min(i)} \]

Secondary data consists of hotspot points through downloading on the eodis modaps website, Baluran National Park fire event points through literature studies, Ground Control Points (GCP) points with coordinate information, existing air temperatures, and existing land cover through field surveys. Existing air temperature is measured in the field at 10:00 WIB - 11:00 WIB as an approach to the crossing time of Landsat 8 imagery, namely at 10:11 AM as many as 3 repetitions.

2.2. Data analysis

Primary data and secondary data that have been collected are analyzed by several methods. Landsat 8 images from the three acquisition times were analyzed through the dNBR analysis, dNDVI analysis, and air temperature calculations. Secondary data such as the existing air temperature were calculated the means between the repetitions. The average value is then validated to the air temperature that was processed by Landsat 8 imagery and presented in the form of equations and graphs. The formula of dNBR index analysis, dNDVI analysis is as below:
The calculation of air temperature using the band-10 Landsat 8. There are several calculation steps as below:

2.2.1. Temperature brightness (TB) and temperature surface (TS)

$T_b = \frac{K_2}{\ln \left( \frac{K_1 + 1}{L_{\lambda}} \right)}$ ; $T_s = \frac{T_b}{1 + \left( \frac{\lambda T_b}{\delta} \right) x \ln(\varepsilon)} \quad (2.2.1)$

Reference (2.2.1)

$T_b$ : tempereture brightness (K)  \hspace{1cm} \delta : \frac{hc}{\sigma} \text{ (as much as 1.438 x 10}^{-2} \text{mK)}

$K_1$ : 1st calibration constant in band 10  \hspace{1cm} c : \text{light’s speeds (2.998 x 108 m.sec}^{-1})

$K_2$ : 2nd calibration constant in band 10  \hspace{1cm} h : \text{Planck’s constant (6.26 x 10}^{-34} \text{J sec)}

$L_{\lambda}$ : the spectral radiations received are analyzed  \hspace{1cm} \lambda : \text{wavelength of band-10}

$T_s$ : temperature surface (K)  \hspace{1cm} \sigma : \text{Stefan Boltzman’s constant (5.67 x 10}^{-8} \text{Wm}^{-2} \text{K}^{-4})

\varepsilon : \text{object emissivity}

water body =0.98; GCV =0.95; non-GCV =0.92 [10], [27].

2.2.2. Alebdo

$\alpha = \frac{\pi L_{\lambda}}{ESUN \cos \theta}$ \quad (2.2.2)

Reference (2.2.2)

$L_{\lambda}$ : the spectral radiations received at any pixel are analyzed  \hspace{1cm} d : \text{astronomical distance of the sun to earth}

ESUN : average spectral solar irradiance  \hspace{1cm} \theta : \text{zenith angle (90}^0 – \text{image elevation angle)}

band 2 : 2067, band 3 : 1893, dan band 4 : 1603 [5]

2.2.3. Shortwave radiation, longwave radiation, and net radiation

$R_{S_{\text{out}}} = \pi L_{\lambda} \frac{d^2}{\text{band}} \frac{1}{band} ; \quad R_{L_{\text{out}}} = \varepsilon \sigma T_s^4 ; \quad R_{S_{\text{in}}} = \frac{R_{S_{\text{out}}}}{a} ; \quad R_n = R_{S_{\text{in}}} - (R_{S_{\text{out}}} - R_{L_{\text{out}}}) \quad (2.2.3)$

Reference (2.2.3)

$\alpha$ : albedo’s mean  \hspace{1cm} L_{\lambda} : \text{the spectral radiations received at any pixel are analyzed}$

$R_{S_{\text{out}}}$ : reflected shortwave radiation (Wm$^{-2}$)  \hspace{1cm} d : \text{astronomical distance of the sun to earth}$

$L_{\lambda}$ : the spectral radiations received at any pixel are analyzed  \hspace{1cm} R_n : \text{net radiation (Wm}^{-2}$)

$R_{L_{\text{out}}}$ : reflected longwave radiation (Wm$^{-2}$)  \hspace{1cm} R_{S_{\text{in}}}$ : income shortwave radiation (Wm$^{-2}$)

$R_{S_{\text{in}}}$ : income shortwave radiation (Wm$^{-2}$)  \hspace{1cm} d : \text{astronomical distance of the sun to earth}$

1/band : middle value of the i band

band-2 : 0.480, band-3 : 0.560, dan band-4 : 0.655 [26]
2.2.4. Ground heat flux and heat flux left

\[ G = \frac{T_s}{a} (0.0038a + 0.0074a^2) \left[ 1 - 0.98NDVI^4 \right] (Rn) \]

\[ H = \frac{\beta (Rn - G)}{1 + \beta} \]

Reference (2.2.4)

- \( T_s \): surface temperature (K)
- \( \alpha \): albedo’s mean
- \( \sigma \): Stefan Boltzman’s constant (5.67 x 10^{-8} \text{ Wm}^{-2}\text{K}^{-4})
- \( \beta \): bowen ratio value
- \( R_n \): net radiation (Wm^{-2})
- \( \text{body water}: 0.11, \text{building}: 4.0, \text{forest}: 0.33, \text{and other vegetation}: 0.5 \) [14]

2.2.5. Air temperature

\[ T_a = T_s - \frac{Hr_{all}}{\rho_w c_p} \]

Reference (2.2.5)

- \( T_a \): air temperature (C)
- \( T_s \): surface temperature (K)
- \( \rho_w \): moist air density (1.27 Kg.m^{-3})
- \( c_p \): specific heat of air at constant pressure (1004 JKg^{-1} K^{-1})
- \( r_{all} \): aerodynamic resistance (Wm^{-2})

3. Result

3.1. Burned area and fire severity

Baluran National Park is not entirely classified as a burned area. The results of the calculation of the threshold on NBR's value changes show the scattered burned area on pixels that have NBR value changes (dNBR) of 0.0575 – 0.3573 as below (Table 1a). Then, we classified burned pixels into 3 severity classes based on dNBR values with natural break methods. The extent of the burned area in each fire severity class is shown in the following table (Table 1b):

| Table 1(a). Threshold of burned area            | Table 1(b). Fire severity class |
|-----------------------------------------------|---------------------------------|
| Statistic parameters | dNBR | Information               | No | Class       | dNBR       | \( \Sigma \) pixel |
| \( \mu \)          | 0.044 | mean                      | 1  | low burned  | 0.0575 – 0.066 | 13920          |
| \( \sigma \)       | 0.013 | standard deviation        | 2  | light burned| 0.066 – 0.150  | 6042           |
| \( \mu + \sigma \) | 0.057 | threshold of fire area    | 3  | severe burned| 0.150 – 0.357  | 27             |

3.2. Characteristics of fire
Characteristics of fires are explained based on fire severity (Figure 1a-c) and are described based on land cover (Figure 2a-c). The result of analysis NDVI, NBR, and calculating air temperature are used to describe each characteristics of fire.

Fires that occurred in each class indicate that the fire severity can be seen by the increasing value of dNBR based on each class. However, different result is shown by the distribution of NDVI values in each fire severity class. Based on the figure 1b, the value of dNDVI shows a rating that is : light > low > severe. Then, result of calculating air temperature uses value that has been validated between imagery air temperature to field air temperature before. Based on the results of a simple linear regression analysis between field air temperature (Y) and imagery air temperature (X), produces an equation that is \( Y = -0.9731X + 54.537 \), R square = 0.3044, and Multiple R = 0.0926. After extracted in 60 same point, field air temperature ranges from 27.7°C – 36.2°C with mean value is 31.2°C, then imagery air temperature ranges from 22.8°C – 25.2°C with mean value is 24.0°C. The results show that the trend of dTa value is more responsive to the increasing dNBR trend due to vegetation openness in Baluran National Park, which was more influenced by periodic fire events. The trend of dTa value is: low < light < severe. It indicates that the occurred fires which are more severe, cause an increase of air temperature due to the opening of vegetation after the fires.

The other characteristics of fire is also described based on land cover. We classified land cover into 9 types, but there are only 5 land cover types that had identified in the burned areas. The distribution of dNBR values is almost same on each land cover type with a trend value, namely: SV (savanna) > HT (plantation forest) > HS (secondary forest) > HP (primary forest) > BK (shrub). Savanna has extreme dNBR values which is relatively higher than the other land cover types. Similar findings can be seen from the distribution of dNDVI values. Savanna has extreme dNDVI values with trend values, namely: SV > BK > HP > HS > HT. The difference between these two indices is the effect of fire on canopy openness. NBR can respond to canopy openness with fires, while NDVI can respond to canopy openness without fires. The trend of air temperature changes (dT_a) generally shows that more vegetation cover is opened, so the air temperature also will be higher. Vegetation generally has a higher density starting from savanna, shrub, plantation forest, secondary forest and primary forest. The value of dT_a has a trend of: HT > SV > HP > HS > BK.
We used the Student's t-test (One-Sample T Test) at the significance level (alpha = 0.05) with SPSS operations to find out the difference values in each parameters tested. Each parameter has a significantly different value distribution where the value of Sig. (2-tailed) is smaller than 0.05, but the prefire NDVI parameter on each land cover has a Sig. (2-tailed) which is quite large and almost approaches the 0.05 level, which is 0.042.

| Parameter         | t-counting | Sig.2 tailed |
|-------------------|-------------|--------------|
|                   | prefire     | postfire     | prefire     | postfire     |
| NBR               | Fire severity | 454.825 | 15.069 | .000 | 0.004 |
|                   | Land cover types | 248.977 | 290.586 | .000 | .000 |
| NDVI              | Fire severity | 6.887 | -5.004 | 0.02 | 0.038 |
|                   | Land cover types | 2.960 | -27.801 | 0.042 | 0.000 |
| Air temperature   | Fire severity | 50.848 | 36.234 | .000 | 0.001 |
|                   | Land cover types | 55.829 | 93.823 | .000 | .000 |

4. Discussion

4.1. Characteristics of fire based fire severity

The area of fire in Baluran National Park was identified as wide as 1 798.92 ha (low class of 1 252.71 ha, medium class of 543.79 ha, and severe class of 2.43 ha) as mapped in the Figure 3, based on statistics on dNBR values at 51 hotspots in the period 30 April - 7 October 2018. Forest and land fires always have an impact on the reduction of biomass, especially vegetation biomass and changes in soil water content and water content in vegetation. NDVI utilizes the difference in maximum absorption of radiation in band-4 (RED) as a result of the production of chlorophyll pigments and utilizes maximum absorption of radiation in band-5 (NIR) as a result of cellular leaf structure [24]. Another parameter that can describe a fire is the NBR indices. It utilizes band-5 (NIR) and band-7 (SWR 2) which are sensitive to soil and vegetation water content. Opened tree canopy and decreased water content after a fire can be responded well by the SWIR spectrum which has increased it’s reflection [11], [7]. NBR or NDVI values in dense vegetation will produce higher values compared to sparse vegetation or non-vegetation.
An increasing of the NBR_pre can indicate more fuel available before a fire. But the decreasing of NBR_post in each class can indicate how much vegetation is left. Severe class shows the least value of NBR_post because the burned vegetation is quite high compared to low class and light class. The dNBR value that increases in each class, is the result of classification using natural breaks based on the minimum threshold value of the area that can be said to be burning. The tendency of the dNDVI value explains that the NDVI indices is less appropriate to explain the fires that occur in each class of fire. This is consistent with the research of Parwati [17] that NDVI can only detect changes in vegetation without fire activity, but the NBR vegetation indices can explain changes in vegetation by responding to fire events. Vegetation in severe class is secondary forests and plantations forest which have lower chlorophyll forage production from the RED band response than the other two classes which have savanna and shrub cover. However, the both vegetation cover shows a high value of dNBR which indicates the presence of fire activity with charcoal’s traces. The charcoal in mean is the result of the response of the SWIR2 band which has function to respond to low levels of vegetation water and scorched soil after burning [18].

The result of the validation of the image air temperature to field air temperature is quite different due to 2 factors. The first factor is the different image acquisition date (April 1, 2019) from the field survey date (March 15 - March 22, 2019) due to limitations in image acquisition. Moreover, the other factor is the immediate environmental conditions when collecting data in the field which is influenced by climate factors such as wind speed, vegetation temperature around the point, and cloud cover that is not fixed at the point of data collection. The greater the value of cloud cover, causes value of solar radiation smaller, so air temperature on the object becomes lower [1]. The average delta temperature between field measurements and image analysis is 7.1 °C. According to Nemani [15], there is a close correlation between vegetation canopy density calculated by NDVI and air temperature changes (dT_a). However, the results showed that trend of dT_a values is more responsive to the increasing dNBR trend than dNDVI trend. This is due to vegetation openness in Baluran National Park, which was more influenced by
periodic fires. Air temperature ($T_a$) is a derivative of surface temperature ($T_s$). Increasing of $T_s$ is caused by a decrease in reflectance from the SWIR2 response [4]. This explains that $T_a$ is more responsive to vegetation changes in the presence of fire activity, compared to absence of fire activity.

4.2. Characteristics of fire based land cover

Land cover in area management is quite important especially in area management. Fires that occur in Baluran National Park were generally caused by anthropogenic factors [3] which included the management of areas on certain land covers. According to Sutomo [20], other controlled burning in forest cover such as monsoon forests in the rainy season was intended to reduce fuel loads when the dry season arrives. The lack of fire control effects, such as in Kramat and Balanan, caused changes in the composition and structure of vegetation from savanna to tree species composition that resembled vegetation in monsoon forests [23].

Extreme values in dNBR and dNDVI are caused by different factors. According to national park officials in the field, burning activities by people in the savanna in the dry season were aimed to accelerate process of growth of grass for community animal feed. The effect of fire on savannas allow forage grasses to be more dispersed and more productive [19]. The burning activity caused dNBR in savanna to be higher than other cover which was rarely seen burning activity. Higher dNBR values in the forest (plant, secondary and primary) than shrubs has mean that forests have more fuel than shrubs. Factors that cause savanna have extreme dNDVI values are acacia logging activities that invaded savanna areas. The acacia logging activities by the community were not followed by burning activities, because acacia woods were used for firewood needs. According to Marliani [14], utilisation of the most dominant type of forest resources in Baluran National Park was the acacia (Acacia nilotica) species to meet needs of household-scale firewood or resale. Chlorophyll forage production can be well illustrated by NDVI_pre. Savana has NDVI_pre which is greater than forests, because the productivity of chlorophyll in grass leaves is higher than the old trees leaves. The succession of vegetation cover can be illustrated by NDVI_post for 3 days ie the last hotspot (October 4, 2018) until the time of acquisition of postfire images (October 7, 2018). The succession between HS, HT, and BK is relatively the same, while the succession of SV and HP has a quite high regeneration (NDVI = 0.096 and NDVI = 0.091).

Savana has higher wind speed, temperature and fuel load values than forest cover [8]. These findings is accordance with the results of research that showed dT, savanna distribution is greater than primary and secondary forests. However, the value of dT, $T_s$ post and $T_s$ pre in savanna is smaller than plantation forest (HT) because the openness of vegetation caused by fires in the plantation forest. This is indicated by the Baluran National Park's hotspot report. It stated that the Bitakol Resort which was dominated by secondary forests had the most fires (8 of 51 hotspots). As many as 65.6% of primary forest cover was changed to secondary forest. The land cover changes cause $dT_a$ values at HP greater than HS so that the canopy effect on HP is more open to raise air temperature.

5. Conclusion

The burned area in Baluran National Park was identified as wide as 1 798.92 ha based on statistics of dNBR values at 51 hotspots in the period 30 April - 7 October 2018. Fires spread in low (1 252.71 ha), light (543.79 ha), and severe (2.43 ha). Changes in air temperature in Baluran National Park are more responsive to the NBR indices than the NDVI indices due to the pattern of fires has occured periodically every year. The highest air temperature changes are the severe class that change vegetation after burning in the form of a secondary forest entirely. The characteristics of fire in severe class which is dNBR, dNDVI, and $dT_a$ is 0.229, 0.191, and 9.6 °C. The highest air temperature change is also seen by forest plantations (teak forests) which is scattered on the edge of the highway by 8.7 °C and dNBR and dNDVI values of 0.059, and 0.195.
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