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The Need of Monitoring Forest Fires through Burned Area Mapping in Indonesia

AUTHORS INFO
Risty Khoirunisa
Department of Physical Geography and Geoinformatics, University of Szeged, Hungary
Risty.khoirunisa@gmail.com

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Abstract

Forest fires have become a regular phenomenon in Indonesia, especially in the dry season. They can be caused by natural and anthropogenic factor. Since Indonesia's soil, especially Sumatra and Kalimantan, is a peatland type, this type of soil is highly inflammable, thus a small fire can easily spread and become massive. This phenomenon provenly disturbs the balance of the ecosystem and socio-economy of the affected country. Previous forest fires resulted in a higher risk of respiratory problems and increased mortality or the death of infants and children. The loss of biodiversity and the increasing amount of Green House Gas (GHG) Emissions that affected the change of climate is also the effect caused by those. For those reasons, the need of monitoring forest fires is essential, especially in climate change mitigation as fire disturbance is one of the key variables in it. This paper will further discuss the method of monitoring through burned area mapping using remote sensing technique.

Keywords: Remote Sensing, Burned Area Mapping, Forest Fires, Landsat

A. Introduction

Fires are significant factors that contributed to increasing amounts of aerosols and recognized as a major source of greenhouse gases emission which is a vital key to climate change (Andreae, 1991; Knorr et al., 2016; Chuvieco et al., 2019). They have profound impacts on the physical environment including: landcover, land use, biodiversity, climate change and forest ecosystem, and affected the socio-economy system of the area. In densely populated areas, air quality decrease as well as the health, especially the respiratory system. Fires also affect the vegetation and become a significant cause of land use transformation. Massive fires also affect soil erosion and the hydrological cycles (Chuvieco et al., 2019). It damages the ecological value considering the time for regeneration on all the ecosystem services such as soil, vegetation and habitat.

Analysis of fire history data on Global Forest Watch Fires confirms that fires tend to be concentrated on agricultural and peatlands in Indonesia (WRI, 2017). Gellert (1998) stated the fires are the outcome of three decades of opening Indonesia's forests to exploitation and the export of timber products. This pattern of forest exploitation has culminated most recently in the over rapid conversion of large area of Sumatra and Kalimantan into plantations. Gellert summarized in his book that as long as the expansion of plantation grown in Indonesia, the fires will be likely increased, especially during El-Nino years, such as the large fires that happened in 1982-1983, 1997-1998, and 2015.

National Institute of Aeronautics and Space of Indonesia (LAPAN) stated that in September 2019, there are 9.310 hotspots that was identified in Indonesia with the confidence level greater than 80 %. Most of the hotspots for Indonesia occurred in August and September 2019. Until September 2019, Indonesia's National Department of Disaster Management stated that 857.756 hectares burned area was identified. It also gave severe impact on the health of the people in the affected area. There were 885.026 cases reported of severe respiratory infections due to the haze and smog.

The causes of fires are various but are mainly due to human activity while the rest are caused by natural phenomenon, such as lightning and extreme weather. Human related fires are mainly grouped as intentional and unintentional fires. The area of burning is usually marked in dry season with higher surface temperature. For Indonesia, is highly happened during period of July to October, the peak of the dry season. Therefore, the assessment is needed for identifying the best technique to detect fires in the future.

B. Methodology

The research method used in this research is descriptive qualitative method using library research analysis. The analysis used to answer:

1. Why burned area assessment and analysis is important?
2. What best technique to detect fire damaged forested areas using remote sensing techniques?

The chosen papers and articles mostly associated with Landsat Satellite Imageries in fire investigation. Some of them associated with Sentinel and MODIS. A small portion of the research papers is using Advanced Very High Resolution Radiometer (AVHRR) Imageries, such as SPOT and SAR (Synthetic Aperture Radar). The collective paper was chosen from 2000 to 2019 as the paper is written in 2020 from different sources.

C. Findings and Discussion

The Need of Monitoring Fires and Burned Area Mapping

After a catastrophic event of fires in 1997-1998, the severe fires happened again in 2015. From 21 June to 20 October, fires burned more than 2.4 million hectares of land, of which between 0.43 million and 0.67 million hectares was forested (World Bank, 2016). By one independent estimate, on many days the carbon emissions exceeded those of the entire US economy. The fires polluted the air, closed schools and airports, and damaged crops and timber stands. The 2015 fires in Indonesia made the headlines and dominated international news coverage for months. After 2015 fires, 2019 fire is the largest one that happened in Indonesia (figure 1).

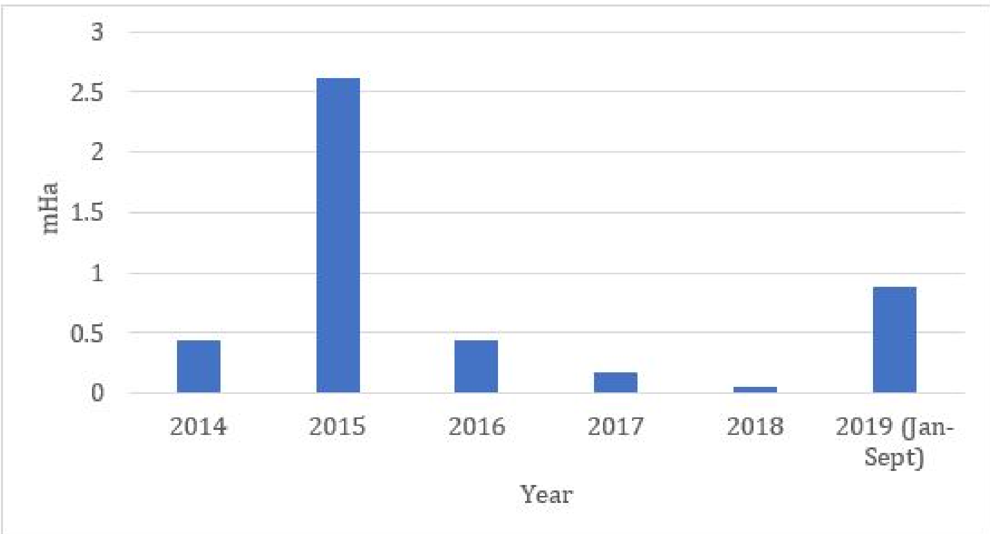

Figure 1. *Total burned area in entire Indonesia by years in million hectares (MOEF 2019)*

A forest fire or wildfire is considered an important disturbance agent, with a long history of shaping landscape patterns and ecosystem processes, relating to both vegetation distributions and physical structures. Large-area of fires can affect climate cycles at a global scale, like what happened in Australia, while, at landscape scales, it influences vegetation structure and pattern (Tran et al., 2018). Assessment of this fire effects is needed to select post-fire treatments, to obtain the information for vegetation recovery monitoring, as well as to provide appropriate variables for future landscape planning (Brewer et al., 2005). Jolly et al. (2015) predicted that the impact of fires is expected to increase in the future due to climate changes. Therefore, it is become relevant to improve the knowledge to foreseen and minimize the impact of the burning fires.

The monitoring of fires and information that extracted from it are necessary to address the climate change issue which are now become the attention of the world, since fire disturbance is considered one of essential climate variables (GCOS, 2016). Policy related to induce fire emission, such as Kyoto Protocol and the agreements at the UN Conference on Climate Change in Paris need the information of fires as a key variable. Therefore, the need of burned area information become important for climate modelling and vegetation recovery monitoring.

Remote Sensing Application for Assessing Forest Fire

There are several different ways to detect fire damaged forested areas using digital image processing, such as classification, Principal Component Analysis (PCA), Spectral Mixture Analysis (SMA), and vegetation indices. In the early year for burned mapping, past research used visual interpretation analysis only from Landsat to validate supervised maximum likelihood classification (Bourgeau-Chavez et al., 2002). Not only by visual, temporal differences also become a good parameter to extract information between pre-fire and post-fire satellite imageries. The maximum likelihood classification was practiced in some research to obtain the burned area information or evaluate other classification methods as a validation tools (Henry, 2008).

Principal Component Analysis (PCA) also has been used since early 1980s for burned area and change detection analysis. Richards (1984), used PCA method for classifying burned area by using an 8-dimensional multi-temporal image dataset. Siegert and Hoffmann (2000) used PCA method for multi-temporal ERS-2 SAR images acquired before and after the fire, while Hudak and Brockett (2004) using a standardized PCA on a Landsat time series dataset consisting of 22 annual images of Landsat from 1972 to 2002 with a simple non-parametric supervised classification and a forward/inverse principal component analysis to enhance the spectral reflectance of burned area.

Another approach that called Spectral Mixture Analysis (SMA) were first applied in burned area mapping in the early 1990s. Sunar et al. (2001) stated that all surface features, such as water, vegetation, soil, have spectral response patterns. If these patterns are unique then the features can clearly be identified from spectral information using remote sensing approach. The spectral vegetation indices analysis method can also be used to detect the change to its reference state (before fires happened) that derived from remotely sensed data and produce a map of the affected area (Mitchell et al., 2017).

Several indices were developed to assess forest fires, such as NBR, NBR2, NBRT, NDMI, and FRI. NBR was developed by Key and Benson (2006) through a joint program between USGS and NPS (US Geological Survey and National Park Services) and the difference between pre-fire and post-fire NBR is become the common method for mapping large fires remotely.

Both of the satellite imageries (Landsat and Sentinel 2) have been used in conjunction for burn severity identification (Mallinis et al., 2018). Landsat imageries widely use to indicate burn severity for years because of its periodical record, accessibility, large coverage, and the variety of spectral wavelengths. Some research also used Sentinel-2 images for validating the accuracy of burned area product result on Landsat (Roy et al., 2019) since Sentinel 2 band has higher spatial resolution than Landsat 8 OLI/TIRS. Another recent development is Proba-V satellites that also can be downloaded from ESA Copernicus, the same source for Sentinel's download. Proba-V was developed by VITO Belgium and can be used for assessing burn scar through vegetation recovery and mapping land cover. The satellite's spatial resolution is 100 meter and it covered the entire earth surface every two days.

While for detecting active fires, some research stated that Landsat and Sentinel 2 have no detection capabilities and rarely overpass when a fire is burning (Schroeder et al., 2016; Roy et al., 2017). 375-m VIIRS (Visible/Infrared Imager Radiometer Suite) from Suomi NPP and 1-km MODIS active fire detections may be used, but they cannot capture or detect the smallest sign of fire due to the small spatial resolution, as they cannot be observed at Landsat-8 or Sentinel-2 spatial resolution (Roy et al., 2017).

Burn Indices Overview

Several indices were developed specially for identifying burn area and its severity, for example Burn Area Index (BAI). The index is computed from the spectral distance from each pixel to a reference spectral point, where recently burned areas converge. BAI is computed as following formula:

$$BAI = \frac{1}{(0.1-Red)^2+(0.06-NIR^2)} \text{.......................................(Martin, 1998)}$$

Garcia and Chuvieco (2004) used BAI for mapping burned areas in Spain, as it showed the greatest sensitivity to discriminate burned areas from other land cover types, combined with NDII (Normalized Different Infrared Index) to avoid confusion with water and cloud shadows. The BAI clarified most confusion between burned areas with vegetation and bare soil covers, while the NDII reduced problems with water and cloud shadows.

Another developed index is Normalized Burn Ratio (NBR) which was formulated in 2005. The formula is similar to a Normalized Difference Vegetation Index (NDVI), except that it uses near-infrared (NIR) and shortwave-infrared (SWIR) wavelengths.

$$NBR = \frac{(NIR) - (SWIR2)}{(NIR) + (SWIR2)} \text{.......................................(Key and Benson, 2006)}$$

NBR Index was designed to highlight burned areas, the formula is similar to NDVI, however they used near-infrared (NIR) and shortwave-infrared (SWIR) wavelengths instead of red band and near-infrared (NIR) band. Vegetation before fires has very high near-infrared reflectance and low reflectance in the shortwave infrared portion of the spectrum (Cocke et al., 2005). On the contrary, burned areas have relatively low reflectance in the near-infrared and high reflectance in the shortwave infrared band.

The difference between the pre-fire and post-fire NBR is used to calculate dNBR, and determine the burn severity level. A higher value of dNBR indicates more severe damage, while areas with negative dNBR values may indicate regrowth following after a fire. The value of NBRI Pre-fire is usually higher than postfire, thus resulting positive dNBR for area that got affected by fire.

$$\text{dNBR} = \text{NBR (Pre} - \text{fire)} - \text{NBR (postfire)} \text{ ....(Key and Benson, 2006)}$$

Value of dNBR can vary from case to case, so interpretation should be validated using visual interpretation or field assessment for the best result. The United States Geological Survey (USGS) with National Park Services (NPS) proposed a classification table to interpret the burn severity in 2006 (figure 2).

Correlations between CBI (Composite Burn Index) that based on field measurement on sampling points and dNBR have been used to demonstrate the sensitivity of dNBR to post-fire effects and to establish numerical thresholds in dNBR data that discriminate severity categories (Cocke et al., 2005). NBR data have been shown to correlate to field-based estimations of fire severity based on some researches. Negative values of dNBR indicate a positive vegetation response (growth) and positive values indicate a negative vegetation response (Eidenshink et al., 2007).

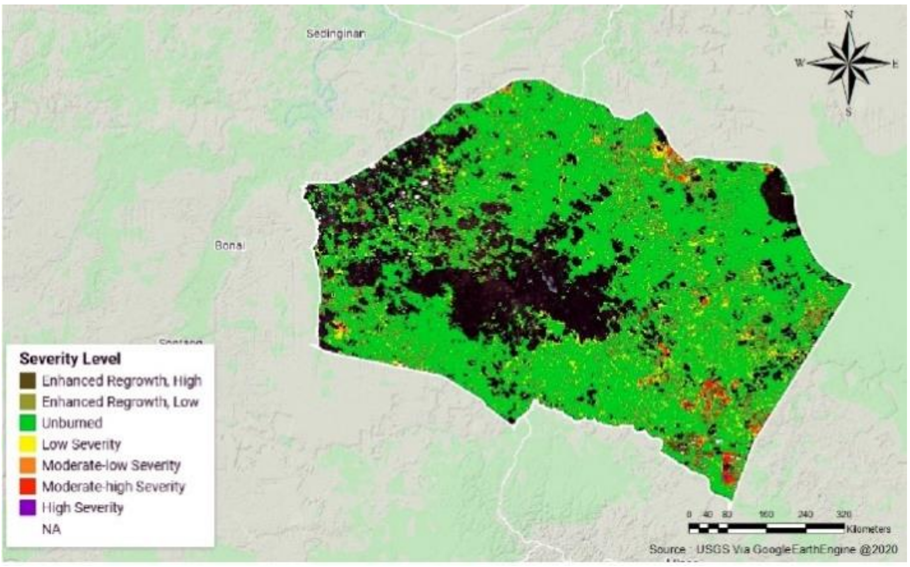

Figure 2. Burn Severity Level Mapping in Bengkalis, Riau in 2019 based on USGS Standard Classification generated from GoogleEarthEngine

Fire parameter and burn severity assessment also can be evaluated using the Relative difference Normalized Burn Ratio (RdNBR) using dNBR and dNBR offset as investigated in study conducted by Morresi et al. (2019). This threshold (RdNBR) was defined by Miller and Thode (2007) as a classification of burn severity class. The dNBR offset was computed by averaging dNBR values within unburned area which were delineated for each study area to minimize changes in reflectance not caused by fire, thus they reduce the disturbance. In this case, they assumed they only calculated and analyse the area that got affected by the fire.

$$dNBR = \frac{(dNBR)*1000)-dNBRoffset}{\sqrt{|NBR^{Prefire}|}} \text{..(Miller and Thode, 2007)}$$

Soverel (2010) compared the accuracy of dNBR versus RdNBR for burn severity classification that indicated a higher overall classification accuracy for dNBR than RdNBR in Western Canada National Parks result also validated previous finding by Wulder et al. (2009) who said that RdNBR did not improve post-fire estimation. Further research by Park et al. (2014) introduced the novel index called as Relativized Burn Ratio (RBR) which very similar in concept to the RdNBR for identifying burn severity (Zheng et al., 2018). It is created to avoid some of the mathematical difficulties associated with the RdNBR equation. Park et al (2014) found that RdNBR alongside with RBR performed better than dNBR in Southwestern US.

$$RBR = \frac{dNBR}{(NBR\ prefire\ +1.001)} \text{...(Park et al., 2014)}$$

RBR adds 1.001 to the denominator ensures that the denominator will never be zero, thereby preventing the equation from falling to calculate. All the indices for determining burn severity is still debated, some researches (Miller and Thode, 2007; Park et al.,2014; Moressi et al., 2019) stated that RdNBR is the best for quantifying, while other researches (Wulder et al., 2009; Soverel, 2010) found that RdNBR did not significantly improve the result compared to dNBR.

Discussion

The findings lead that burned area mapping is important for planning and recovery besides to predict the area which have higher tendency to burn. Burn severity maps can be helpful to predict areas of potential fire hazards (fire-risk mapping), to map fire affected-area, to plan ecosystem rehabilitation and to study vegetation recovery. Severity mapping is likewise of importance for immediate post-fire rehabilitation.

The research paper combined has different result on the best indices based on geography. RdNBR and RBR are performed better than dNBR in United States, however in other regions, dNBR was provenly have higher accuracy that RdNBR and RBR. Therefore, there is a hypothesis that the performance of indices is vary, depends on the region and the satellite imageries which are employed to the index.

One of the researchs also found a novel index which are proclaimed better than dNBR in assessing burned area and forest recovery, it is called IFI (Integrated Forest Index). IFI are provenly performed higher accuracy rather than dNBR in Australia. However, there is no research on IFI in Indonesia to this present day.

In Indonesia, the employment of RdNBR and RBR is not as popular as dNBR and IFI is not yet implemented. Therefore, dNBR still become the best spectral indices to assess fire in Indonesia. With the popularity of Landsat time-series in burned area assessment, it is critical to understand the advantages and limitations of dNBR index. dNBR can become a great index when assessing large forests without residential area or other land cover, however, the accuracy will be likely reduced when assessing small area with less than 500 hectare or the area with the mix of residential area or other land covers. As a result, the identification will be difficult for small forests. RBR is believed to be better in assessing small area of forest. Another limitation of dNBR is water land cover. Water masking becomes essential in dNBR assessment to have greater accuracy in burned area assessment since dNBR is sensitive to water spectral.

D. Conclusion

The urgency of burned area mapping become important as forests will be a vital variable for climate change. The burned area mapping can be used for planning, recovery and predict the future risk of those highly burned area or potential hazard which might be occur. Remote sensing application can be a best tool for assessing the large area of fires. The burned area identification is commonly created by combination of spectral indices such as shortwave infrared and near infrared. The findings found from numerous collective research is dNBR has higher performance compared to other indices such as RdNBR or RBR. Nevertheless, it should be taken consideration that differences in geography, landscape, and type of soils can influence the capabilities of satelites to assess fire. Therefore, the employment of RdNBR, RBR or dNBR might be better in some regions, but not in the other regions. Further researches need to be carried out to gain the information regarding the capability of these indices and compared them between region with different topography to find out their correlation.

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