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Research

Burned area mapping in Dendang District, Tanjung Jabung Timur Regency using sentinel-2

Galih Citra Yogyanti [1,*]

1 Gadjah Mada University, Jalan Kaliurang, Bulaksumur, Yogyakarta 55281, Indonesia

* Correspondence: galihcitrayogyanti@mail.ugm.ac.id

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Abstract

Remote Sensing is a way to provide information efficiently both in terms of cost and time. In addition, the use of remote sensing in mapping the burned area can be carried out on a large scale but with a fast time for the prevention of land fires. Monitoring of forest fires is carried out to see locations that often become fire hotspots every year and to prevent frequent land and forest fires.The method used in this study is to map the burned area using multi-temporal data using the Normalized burning Ratio and Normalized burning Ratio 2 indices from Sentinel-2 images in May and September 2019. The trend data can be used to evaluate the moratorium on forest business permits or a peatland. Sentinel 2 has a higher spatial resolution of 20 meters compared to other multispectral images that can be accessed easily and free of charge, so it is suitable to be applied in areas that are not too large and minimizes the value of estimation errors, using Sentinel 2 imagery which has 13 channels will Selected several channels that can be used for index transformation, namely the NBR (Normalized Burn Ratio) and NBR2 (Normalized Burn Ratio2) indexes, both indices utilize Near Infrared, SWIR1, and SWIR2 channels which can provide information about the area after land fires,The research results obtained that burned areas are often identified as barren land, such as peat canals or vacant land. This is because the spectral reflection characteristics of objects in burnt areas are the same as those in non-vegetated land areas when the NBR index is transformed using the NIR, SWIR1 and SWIR2 channels.

Keywords: forest and land fires; NBR indices; sentinel-2

1. Introduction

Environmental function decline caused by forest and land fires is a domino effect of socio-economic problems. The increasing population is not stable by the availability of materials to fulfill daily needs, both food, clothing and shelter. The socio-economic disparity factor has resulted in many people lacking funds for land preparation, so they choose to use the slash and burn method to fulfill their needs. According to Syaufina (2008), forest and land fires in Indonesia are almost triggered by human activities, both intentional and unintentional, while natural factors such as air temperature, relative humidity, wind, and rainfall are supporting factors for fires in tropical countries. Human activities in fulfillment of daily needs and land conversion often lead to the clearing of forest areas which become one of the most susceptible accesses to encroachment if there is no control from the relevant government. Meanwhile, meteorological and ecological conditions such as friction of dry twigs that produce fires or fires due to lightning trounce are almost impossible in Indonesia with a tropical climate. Most of Indonesia's land area is surrounded by oceans. The nature of the humid tropical climate means that if there is a lightning strike on fuel on land, it will always be followed by rain, so forest and land fires caused by lightning trounce are very unlikely to occurs.

Forest and land fires result in material losses and also have an impact on health such as ARI caused by severe fire smoke pollution. In the forest and land fires in September 2019 from the results of monitoring the Air Pollution Standard Index (ISPU) Air Quality Monitoring System (AQMS) of the Jambi City Environment Service, air quality in Jambi at night resulted in a measurement of particulate concentrations of PM 2.5, above the quality standard with a value of 353 with a dangerous category. It also causes severe air pollution in several Southeast Asian countries (Liputan 6, 2019).

Most of the forest and land fires that occur on Kalimantan and Sumatra peatlands with very high organic matter content. Besides that, secondary forest is also a fire-prone area, because it has become an open area (Yusuf et al., 2019). Forest and land fires in Indonesia often occur, because Indonesia is a country with large areas of secondary forest and peat. Dendang sub-district is one of the sub-districts in the administration of Tanjung Jabung Timur Regency, Jambi Province with an area of 348.43 km2 of which almost half of the area is peatland with an area of 189.62 km2.

Peatlands are a unique type of soil because they are very deep horizon, contain a lot of dead plant remains and are mostly water. When it rains, peat stores a lot of water and during the dry season the water is released slowly to meet the water supply. If peat is not managed properly, it has the potential to release carbon into the air and cause climate change. In addition, if the peat is no longer able to store water, it will cause the area to burn easily due to drought. Water management on peatlands is an important aspect in maintaining soil fertility. Starting from land preparation carried out without burning or the No Burn Policy, and regulated water level conditions through canals that are designed in such a way.

Forest and land fires are one of the problems that until now have not been properly resolved. Remote sensing is a way to provide information efficiently both in terms of cost and time. In addition, the use of remote sensing in forest fire areas can be carried out on a large scale but in a short time for overcoming and preventing land fires. Fawzi and Jatmiko (2018) state that the basis of remote sensing for forest fires is the energy radiated when a forest fire occurs, about 10-20% of the energy generated is radiated away from the location of the fire and as electromagnetic radiation with different wavelengths, thus enabling recordings by remote sensing sensors.

Keeley (2009), defines fire intensity as the energy released during various phases of a fire, including reaction intensity, fireline intensity, temperature, residence time, radiant energy and others for different purposes. Measurement of loss of organic matter due to fire intensity is divided into two, namely Fire Severity and Burn Severity. Fire severity refers to the loss or decomposition of organic matter, both above ground and below ground, but this term is only used for forest fires where the vegetation is dominated by trees that do not have the ability to regrow. Remote sensing applications used to assess burned areas usually use the term burn severity. Remote sensing data used is by lowering the index of the spectral reflection known as the Differential Normalized Bruning Ratio (dNBR). Several indices used to view burnt areas are the NBR (Normalized Burn Ratio) and NBR2 (Normalized Burn Ratio2) indexes, both of which use the ratio of subtraction and addition of Near Infrared and SWIR2 channels for NBR, as well as the ratio of subtraction and addition of SWIR1 channels. and SWIR2 for NBR2 which can provide information on the area of the former land fire.

In certain, this study aims to map the burned area by combining Sentinel 2 multitemporal images using the NBR and NBR2 indices. Besides that, knowledge is needed to know the extent of the transformation ability of the index in mapping the burned area in the study area. The results of this study are expected to be a reference in mapping the burned area by combining Sentinel 2 multi-time images using an index transformation that can provide information on post-fire areas. The results of this study can also be used as a method for mapping burned areas to support post-fire response in Indonesia.

2. Methods

2.1. Study Area

Dendang District is one of the districts located in the administrative area of Tanjung Jabung Timur Regency, Jambi Province with an area of 477,17 km2. Dendang sub-district consists of 6 villages and 1 sub-district. Dendang District area is bordered by the East Muara Sabak District and the Rantau Rasau District, in the east by the Berbak District, in the south by the District. Muaro Jambi, in the west is bordered by the Muara Sabak Barat sub-district. Most of the residents of Dendang Subdistrict make a living as farmers. The area of rice harvested in 2019 in Dendang District is 3,432 ha. In 2019, the number of large-medium companies in Dendang District was 8 companies. While the number of small industries and home businesses is 53 businesses (Central Bureau of Statistics, East Tanjung Jabung Regency, 2020).

The land cover of Dendang District mostly covers form of plantations and swamp shrubs with peatland ecosystems, makes the area in most of Dendang District become areas of frequently fires during the dry season. The government has carried out fire prevention and control, such as a peatland moratorium since 2011 and the Desa Peduli Gambut Program which has been run by the Peatland Restoration Agency (BRGM) since 2017 as an effort to make villages a center for restoration activities. Dendang District itself already has 4 Desa Peduli Gambut, namely Rantau Indah, Jati Mulyo, Kandis Dendang City and Catur Rahayu. In addition, Dendang District also has 22 canal blocks to regulate water in peatlands and maintain ground water in order to increase the water storage capacity of the canal body and its surroundings so that the surrounding peatlands remain wet and burnt. The study area in this paper can be seen in Figure 1.

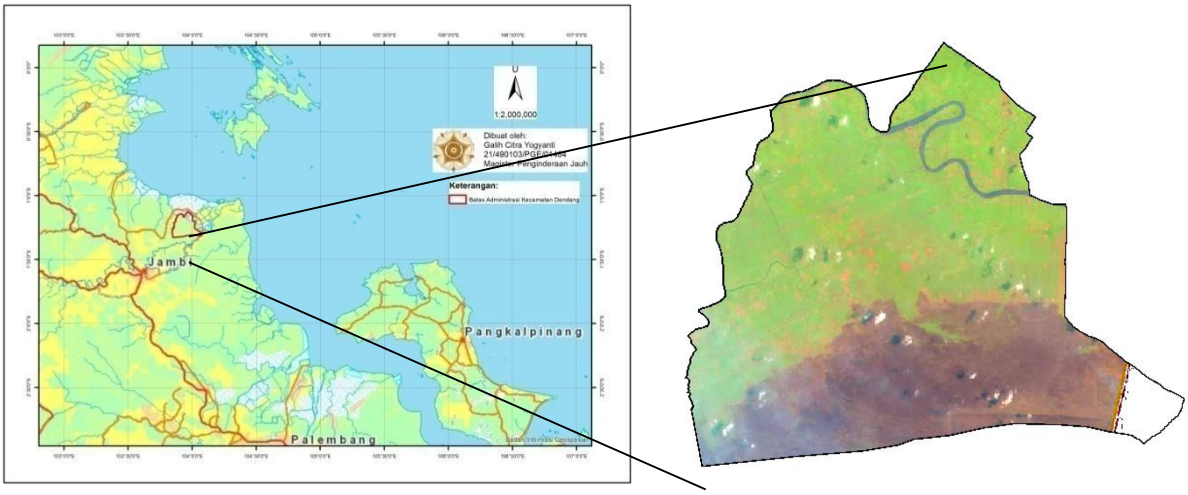


Figure 1 Study Area of Dendang District

2.2 Data

This study uses Sentinel 2B Level 1C tile T48MUD image scene on May 6 2019 as input data for events before the fire and image scene on September 8 2019 as input data for events after the fire. In the study conducted, there was blank data on the adjacent tile on the same date, so that the image mosaic process was not carried out even though it was included in the study boundary at the administration of the Dendang District. Sentinel-2 Multispectral Imagery has 13 channels consisting of four channels with a spatial resolution of 10 meters, six channels with a spatial resolution of 20 meters and three channels with a spatial resolution of 60 meters. The Sentinel Level-1C product is generated from the use of the Digital Elevation Model (DEM) so that the Level data has been systematically corrected geometrically. The radiometric measurements per pixel on this product are provided in the Top Of Atmosphere (TOA) reflectance so that TOA correction is still needed to get the reflectance value.

Based on research conducted by Castillo et al. (2020) using Landsat 8 and Sentinel 2 data in monitoring forest fires in Northeastern Peru, Amazon, Sentinel-2 imagery has produced comparatively clearer forest fire scars with respect to higher spatial, temporal resolution (5 days) and has greater accuracy. So that in this study, in addition to the availability of data on cloud-free pre fire and post fire date coverage, the use of Sentinel 2 imagery is considered to see the ability of higher spatial resolution at a spatial resolution of 20 meters. The Level-1C product also provides Cloud Masks data that can be used to separate the cloud from the study object. Other supporting data are hotspot data from satellites from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra and Aqua satellites for a period of 3 days and land cover maps from the Ministry of Environment and Forestry which will be used for accuracy test.

Table 1 Data Research

No	Data	Type	Scale/Resolution	Source
1	Sentinel 2 MSI Level 1C	Raster	20 x 20 m	https://earthexplorer.usgs.gov/
2	Data Hotspot	Vector	Point	https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms
3	Peta RBI	Vector	1 : 25.000	https://tanahair.indonesia.go.id/
4	Peta Tutupan Lahan	Vector	1 : 25.000	Kementerian Lingkungan Hidup dan Kehutanan

2.3 Method

The method used in this study is to map the burned area using multi-temporal data using the Normalized burning Ratio and Normalized burning Ratio 2 indices from Sentinel-2 images in May and September 2019. The platform used for analysis is ArcGis Pro as a platform for determining spectral indices, data visualization, and accuracy tests, and the Envi Classic 64 Bit platform to see the separability between classes.

Spectral vegetation indices using the formula (ρNIR SWIR) / (ρNIR +ρSWIR) has been widely used to indicate the humidity condition of vegetation. NIR and SWIR are defined as near infrared (NIR) and short infrared (SWIR) reflectance respectively, there are a total of 13 indices using the same formula from 1981-2004. Ji et al (2011) reviewed the definitions of each term, associated sensors and channel specifications. In this study it was found that the index consists of three different SWIR wavelengths (1.2–1.3 m, 1.55–1.75 m or 2.05–2.45 m).

Ji suggests four criteria as guidelines for selecting the right term for the index (NIR SWIR) / (NIR+SWIR): (1) The index should not be named with the associated sensor or channel. (2) The use of these names is widely accepted in the remote sensing community. (3) Three different names may be used, which correspond to the three SWIR regions reflecting different environmental characteristics. (4) The priority rules in scientific nomenclature must be followed. Thus, three terms are considered to represent these three SWIR variants. Considering the spectral representation, popularity of the term and priority rules in scientific nomenclature, NDWI represents in naming the use of 1.2–1.3 m SWIR channels, NDII represents in naming the use of 1.55–1.75 m SWIR channels and NBR represents in naming usage 2.05–2.45 m SWIR channel. NBR uses a longer range of SWIR band reflectance (2.05–2.45 m), these channels are provided by MODIS on band 7 channel, Landsat on band 7 channel, ALI on band 10 and CBERS on band 8. NBR is a popular index for mapping burn severity, NBR is the recommended name for the index when the range of values on the SWIR channel is greater than 2.0 m.

All of the 13 indices using the same formula from 1981–2004, for the longer SWIR region (2–3 m), only one index was introduced. This index was first used by López García and Caselles in 1991 to map forest fires and monitor vegetation regeneration in burned areas with Landsat TM data. A few years later, Key and Benson in 1999 named this index Normalized Burn Ratio (NBR). Because in Landsat TM the SWIR channel used has a range of 2.08-2.35 m. Then this index can be used on Sentinel 2B by selecting SWIR2 which has a range of 2.10-2.28 m. This index is normalized from the NIR channel which represents the vegetation condition and SWIR2 for the burned area which emits the spectral value of the burned area. The equation used is as follows:

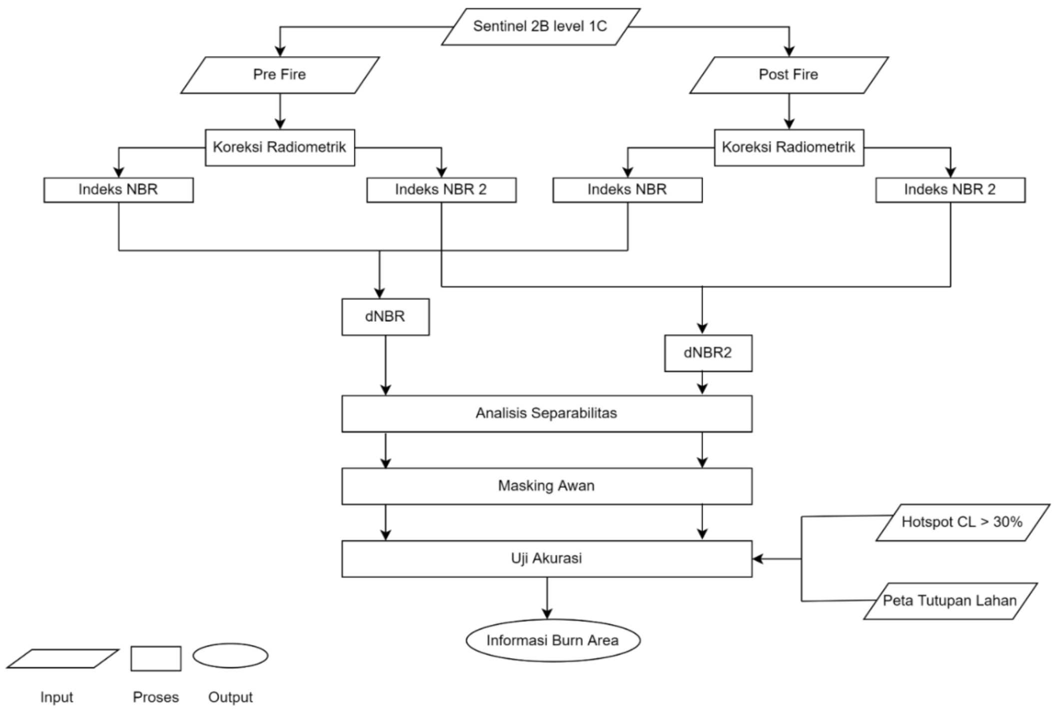
$$NBR = \frac{NIR - SWIR2}{NIR + SWIR2} \quad (1)$$

Whereas, the Normalized Burn Ratio 2 Index was developed by M. J. L. García and V. Caselles in 1991 using a comparison of the Shortwave Infrared 1 (SWIR1) channel in the 1.56-1.65 m wavelength range and Shortwave Infrared 2 (SWIR2) in the 2.10-2.28 m wavelength range. Sentinel 2 imagery. This index is normalized from the SWIR2 channel which emits the spectral value of the burnt area and the SWIR1 channel to see the revegetation of the burned area. The equation used is as follows:

$$NBR_2 = \frac{SWIR_1 - SWIR_2}{SWIR_1 + SWIR_2} \quad (2)$$

Furthermore, the indice is calculated from each temporal image of the time of coverage before the fire and after the fire, then the dNBR and dNBR2 calculations are carried out to see the change in the area that has not been burned and the area burned. Accuracy tests were carried out with hotspot data from NASA's Fire Information for Resource Management System (FIRMS) distributing Near Real Time (NRT) fire or thermal anomaly data within 3 hours of satellite observation from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra and Aqua satellites. This data can be used to test the accuracy of the NBR and NBR 2 indexes in mapping burnt areas. In addition, land cover data from the Ministry of Environment and Forestry is also used for cross validation at the point of unburned areas. The research flow chart in this study can be seen in Figure 2.

Figure 2 Flowchart of the proposed method for mapping burned area using Sentinel-2 satellite imagery



3. Results and Discussion

After the radiometric correction stages were carried out on the two pre-fire and post-fire image coverage, then the NBR and NBR2 index transformations were carried out. The results of the transformation of the NBR and NBR2 indices can be seen in Figure 3. The dNBR value can vary from one case to another so that in the study conducted interpreting the map that can be seen in Figure 4 refers to the classification proposed by the United States Geological Survey (USGS) to interpret fire severity level (burn severity), which consists of 7 classes “High Severity”, “Miderate high severity”, “Moderate-Low Severity”, “Low Severity”, “Unburnedt”, “Enchanced Regrowth-Low”, and “Enhanced Regrowth-High”. Based on the classification carried out, for dNBR it produced 22,118.36 Ha or an area of 68% and for dNBR2 it produced 14,647.6 Ha or an area of 45% of the total area with the detailed area of each class can be seen in table 2.

The radiometric correction stage is carried out on two coverages of pre fire and post fire images, then the NBR and NBR2 indice transformations are carried out. The results of the transformation of the NBR and NBR2 indices can be seen in Figure 3. The dNBR value can vary from one case to another so that in the study carried out the interpretation of the map that can be seen in Figure 4 refers to the classification proposed by the United States Geological Survey (USGS) to interpret burn severity, which consists of 7 classes “High Severity”, “Miderate-High Severity”, “Moderate-Low Severity”, “Low Severity”, “Unburned”, “Enhanced Regrowth-Low”, and “ Enhanced Regrowth-High”. Based on the classification carried out, 22,118.36 hectares for dNBR or 68% were produced and for dNBR2 14,647.6 hectares or 45% of the total area, details of each class area can be seen in table 2 .

Table 2 Burn Severity Level dNBR and d NBR2 at Dendang District

Klasifikasi	**dNBR**		**dNBR$_2$**	
	Area (Ha)	**Percent**	**Area (Ha)**	**Percent**
Unburned	10517.04	32%	18052.92	55%
Low severity	10844.48	33%	5536.8	17%
Moderate low severity	2425.72	7%	6954.8	21%
Miderate high severity	1882.24	6%	2082.52	6%
High severity	6965.92	21%	73.48	0%
Cloud		0%		0
Total	32635.40	100%	32700.52	100%

Changes that have negative values include land degradation due to the impact of small fires that cause a decrease in the vegetation population in the burned area and deforestation which indicates a change from vegetated land (forest and bush) to open land. Meanwhile, changes in land cover in a positive direction include indications of regrowth which may occur in bush areas that previously experienced light fires and began to show regrowth, as well as changes from vacant land to shrubs.

Unvegetated lands such as peat canals or open area are often identified as burnt areas. This is due to the transformation of the NBR indice using the NIR, SWIR1 and SWIR2 channels. The spectral reflection properties of burnt area objects are similar to those of unvegetated land areas. The reflection of the SWIR2 channel emits spectral values from the burned area (non-vegetated area) and the SWIR1 channel to reflect the spectral value of the revegetation of the burned area, while in the NIR channel it is influenced by the absorption of the internal structure of the leaves in the sponge tissue. It can be seen from the indices transformation carried out, the NBR indice is good at distinguishing smoky burned areas from the severity of other burnt areas. While the NBR2 indice is good at distinguishing burned areas from vegetated objects, and not too dominant in reflecting burned areas with high severity (high charcoal).

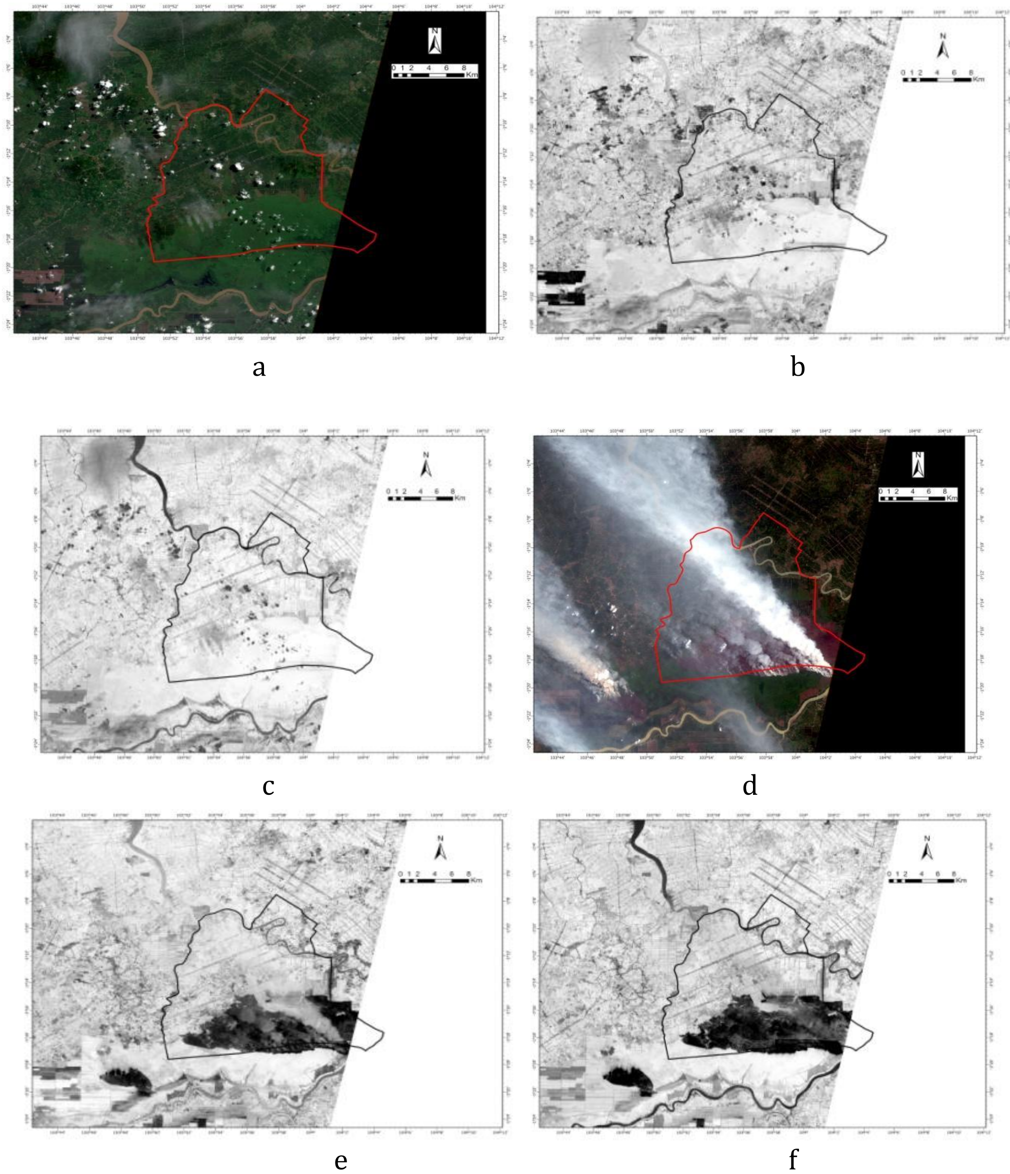


Figure 3. a. RGB Pre Fire, b. NBR Pre Fire, c. NBR2 Pre Fire, d. RGB Post fire, e. NBR Post Fire, f. NBR2 Post fire

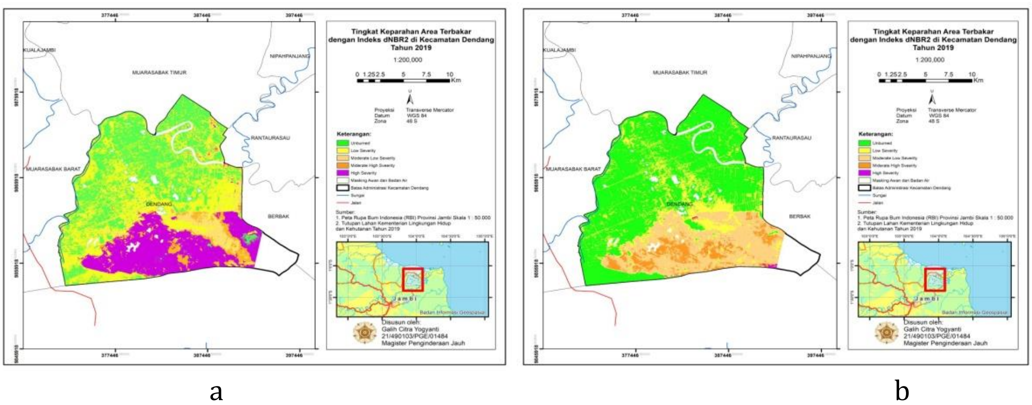


Figure 4; a. dNBR, b. dNBR2

For the fire sample test points, a combination of hotspot points is carried out within a period of three days, to see the hotspot points the day before the post fire image coverage used and the hotspot points the day after the image coverage used. In Hafni's research (2017), it is stated that hot spots are an indication of the potential for fires to occur, but not necessarily fires. Hotspots can indicate a fire event, if the hotspots cluster at a location and/or the hotspots occur three or more days in a row in a period of time. Visually, fire events can also be identified by the presence of fire smoke with a chimney-like pattern.

After obtaining classifications of burnt areas and clouds, an accuracy test was carried out from 131 random points with 55 hotspot points with a confidence value above 30% from MODIS for three days starting from 7 September 2019 to 9 September 2019 as a binary value and 76 points based on the land cover map. The aim is to see how big the assessment of the fire incident assessment is by calculating the index generated from satellite imagery. The results of the dNBR accuracy test are shown in table 3 and the results of the dNBR2 accuracy test are shown in Figure 5.

	Unburned	Burned	TOTAL	EC	PA
Unburned	**44**	8	52	0.15	85%
Burned	32	**47**	79	0.41	59%
TOTAL	76	55	91		
EO	0.42	0.15			
UA	58%	85%			OA = 69% KC = 0,41

Keterangan:
EO : Error Omission
EC : Error Commision
UA : User Accuracy
PA : Produsen Accuracy
OA : Overall Accuracy
KC : Kappa Coefficient

(a)

	Unburned	Burned	TOTAL	EC	PA
Unburned	**67**	20	87	0.23	77%
Burned	9	**35**	44	0.20	80%
TOTAL	76	55	102		
EO	0.12	0.36			
UA	88%	64%			OA = 78% KC = 0,53

Keterangan:
EO : Error Omission
EC : Error Commision
UA : User Accuracy
PA : Produsen Accuracy
OA : Overall Accuracy
KC : Kappa Coefficient

(b)

Figure 5. Confussion Matrix a. dNBR, b, dNBR2

The confusion matrix analysis was carried out to see the accuracy value between indices calculations and field conditions, which in this study used hotspot data and land cover data as ground truth data (Figure 5 and Figure 6). Land cover data is used as test data to see the relationship between the spectral reflection of land cover which is a burned area and vacant land. In the study area, the burnt area detected in the post fire image is a swamp bushland cover which is a peatland with a waterlogged wetland ecosystem so that plant material cannot decompose completely and becomes a combustible fuel that is difficult to extinguish. Result of dNBR shows an overall acuracy of 69% which shows the overall accuracy of the reflectance value of the resulting image under field conditions. The kappa coefficient is 0.41, which means that the classification results are able to avoid 41% of errors that will appear in the field classification. There are 32 classes of unburned land which are classified as burned land class. This error occurs because a lot of vacant land is still classified in burned areas.

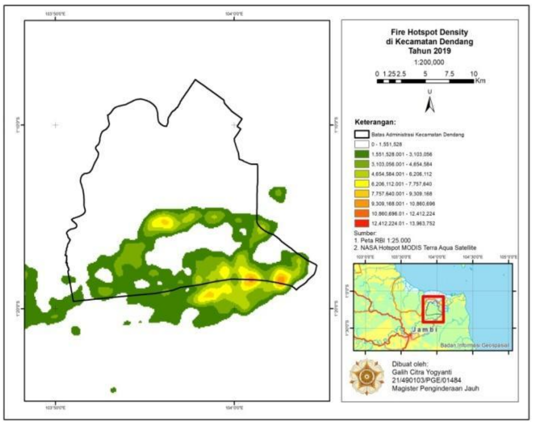


Figure 5. Fire Hotspot

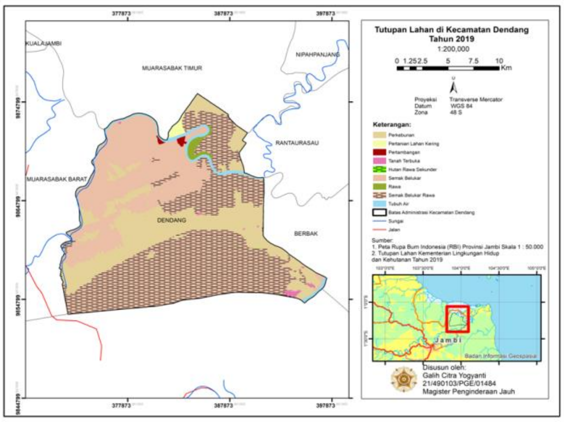


Figure 6. Land Cover Dendang District

The confusion matrix analysis performed for dNBR2 shows an overall acuracy of 78% which indicates the overall accuracy of the reflectance value of the resulting image under field conditions. The kappa coefficient is 0.53 which means that the classification results are able to avoid 53% of errors that will appear in the field classification. The small kappa coefficient of the two confusion matrices is carried out because the random sampling for each class is not evenly distributed. Similar to the dNBR index, there were still commission errors and ommission errors in other unburned areas which were also detected as burned areas. There are a total of 9 classes of unburned areas that were detected as burnt areas. Rachmawan et al. (2017) has study regarding the NBR indices experiment to determine deforestation activity in Riau, the NBR indice not only shows deforestation activity due to burning trees but also clear cutting, the indice value of land experiencing forest fires is higher than land experiencing deforestation due to illegal logging. As also discussed in the research of Cicala et al., (2018) that the approach to detecting changes with indices, such as the NBR and NDVI indices, shows that the performance of the two indices is comparable. It is therefore important to consider that analyzes comparing several indices are not susceptible to false positive results, because the changes detected could be caused by other phenomena and not by burnt marks only.

4. Conclusions

Unvegetated lands such as peat canals or vacant land cover are often identified as burnt areas. This is because in the transformation of the NBR index using the NIR, SWIR1 and SWIR2 channels, the spectral reflection properties of the burned area object are the same as that of the unvegetated land area. The NBR index is good at distinguishing smoky burned areas from the severity of other burnt areas. While the NBR2 index is good at distinguishing burned areas from vegetation objects, and not too dominant in reflecting burned areas with high severity (high charcoal). The dNBR2 index has an Overlall Accuracy of 78%, which is greater than the dNBR of 69%, and dNBR2 has a Kappa coefficient of 0.53 which is greater than the dNBR of 0.41.

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References

Badan Pusat Statistika (Central Bureau of Statistics) Kabupaten Tanjung Jabung Timur. (2020). Kecamatan Dendang dalam Angka 2020.

Barboza Castillo, E., Turpo Cayo, E. Y., de Almeida, C. M., Salas López, R., Rojas Briceño, N. B., Silva López, J. O., ... & Espinoza-Villar, R. (2020). Monitoring wildfires in the northeastern peruvian amazon using landsat-8 and sentinel-2 imagery in the GEE platform. ISPRS International Journal of Geo-Information, 9(10), 564. https://doi.org/10.3390/ijgi9100564

Cicala, L., Angelino, C. V., Fiscante, N., & Ullo, S. L. (2018, March). Landsat-8 and Sentinel-2 for fire monitoring at a local scale: A case study on Vesuvius. In 2018 IEEE International Conference on Environmental Engineering (EE) (pp. 1-6). IEEE. https://doi.org/10.1109/EE1.2018.8385269

Fawzi, N. I., & Jatmiko, R. H. (2018). Penginderaan jauh sistem termal dan aplikasinya. Yogyakarta: Penerbit Ombak.

Hafni, D. A. F. (2017). Estimasi luas kebakaran dan emisi karbon akibat kebakaran hutan dan lahan gambut di Kabupaten Siak, Provinsi Riau. Bogor: Institut Pertanian Bogor.

Ji, L., Zhang, L., Wylie, B. K., & Rover, J. (2011). On the terminology of the spectral vegetation index (NIR− SWIR)/(NIR+ SWIR). International journal of remote sensing, 32(21), 6901-6909. https://doi.org/10.1080/01431161.2010.510811

Keeley, J. E. (2009). Fire intensity, fire severity and burn severity: a brief review and suggested usage. International journal of wildland fire, 18(1), 116-126. https://doi.org/10.1071/WF07049

Lailan Syaufina. (2008). Kebakaran HUtan dan Lahan di Indonesia Perilaku api, penyebab dan dampak kebakaran (Printing 1.). Malang: Bayumedia Publishing.

Liputan 6 (2019). Karhutla Hampir Tiap Hari, Kualitas Udara di Jambi Makin Berbahaya. https://www.liputan6.com/regional/read/4057653/karhutla-hampir-tiap-hari-kualitas-udara-di-jambi-makin-berbahaya [accessed 22 April 2022].

Rachmawan, I. E. W., Kiyoki, Y., & Sasaki, S. (2017). An automatic feature extraction method of satellite multispectral images for interpreting deforestation effects in soil degradation. International Journal on Advanced Science, Engineering and Information Technology, 7(2), 676-687. http://dx.doi.org/10.18517/ijaseit.7.2.2174

Santi, N. A., Jaya, I. N. S., & Saleh, M. B. (2019, December). Measuring the forest cover change in burned area using change vector analysis approach. In Sixth International Symposium on LAPAN-IPB Satellite (Vol. 11372, pp. 413-421). SPIE. https://doi.org/10.1117/12.2540708

Yusuf, A., Hapsoh, H., Siregar, S. H., & Nurrochmat, D. R. (2019). Analisis Kebakaran Hutan Dan Lahan Di Provinsi Riau. Dinamika Lingkungan Indonesia, 6(2), 67-84. https://doi.org/10.31258/dli.6.2.p.67-84