Geographica: Science and Education Journal
GSEJ
Website: http://usnsj.com/index.php/geographica
Email: geographica_gsej@usn.ac.id

BURNED REGION ANALYSIS USING NORMALIZED BURN RATIO INDEX (NBRI) IN 2019 FOREST FIRES IN INDONESIA

CASE STUDY: PINGGIR-MANDAU DISTRICT, BENGKALIS, RIAU, INDONESIA

AUTHORS INFO

Risty Khoirunisa
Faculty of Physical Geography and Geoinformatics, University of Szeged, Hungary
Risty.khoirunisa@gmail.com
(+62) 82242466541

Dr. Mucsi Laszlo
Head of Department of Physical Geography and Informatics, University of Szeged, Hungary
mucsi@geo.u-szeged.hu
(+36) 305352488

ARTICLE INFO

ISSN: 2716-4837
Vol. 2, No. 1, December 2020
URL: http://usnsj.com/index.php/Geographica

Suggestion for the Citation and Bibliography
Citation in Text:
Khoirunisa and Laszlo (2020)
Bibliography: Khoirunisa, R., Laszlo, M. (2020). Burned Region Analysis using Normalized Burn Ratio Index (NBRI) in 2019 Forest Fires in Indonesia (Case Study: Pinggir-Mandau District, Bengkalis, Riau, Indonesia) *Geographica: Science & Education Journal, 2* (1, December), 1-9.

Abstract

Forest fire is a hazard that common to happen in Indonesia every year, whether from natural or human-induced factor. These fires can be uncontrollable and destruct the forest. Furthermore, these can affect the health of the people, the biodiversity, the disruption in transportation and the socioeconomic of the affected region. The total area calculated was burned is 875.756 hectares in the entire country in 2019, the biggest lost after 2015. Thus, the study conducted in some affected area in Riau Province, Sumatra, Indonesia, namely Pinggir-Mandau District, Bengkalis, where consistently suffered from the fire. The study objective was to determine the total burned area in study area and their severity level as well as to obtain the tendency of the land cover of burned area. The study of the burned area was investigated using a formulated index called NBRI (Normalized Burn Ratio Index) that based on Near Infrared (NIR) and Shortwave Infrared (SWIR) spectral reflectance of Landsat 8 OLI/TIRS Satellite Imageries. It is found that about 4,7 %, or 11.014 hectares of the area of the study which was about 234.864 hectares was burned. 90,3 % of the burned area was located in the vegetated area, especially forest area with 50,25 % of those cover the burned area. The validation was using visual interpretation based on SPOT 7 pansharpened images resulted in acceptable agreement with kappa coefficient value of 0,83.

Keywords: Forest Fire, NBRI, dNBR, Burn Severity, Spectral Indices, Landsat

A. Introduction

Forest fire in Indonesia is a regular phenomenon in Indonesia since it is located in the tropical climate area. Based on citation, most of the fire are by anthropogenic reasons. It was stated by National Department of Disaster Management in Indonesia that 80 percent of burned area in the past event changed to the plantation. Thus, it can be concluded that the most significant factor that contributed to the fires is human activity. It often uncontrollable, leading to the destruction of large areas of forest.

Forest fires were considered to be a concern to reach sustainable development goals because of their contribution to greenhouse gas emissions, and their impact on biodiversity and ecosystem. Based on USAID (United States Agency for International Development) report in 2016, the 1997-1998 El Niño event in Indonesia that leads to major forest fires resulted in the regional haze, air pollution, thousands of hospitalizations, and an estimated 5-10 billion USD in economic losses at the national level. It raised attention worldwide and gave an impact to the neighboring country such as Malaysia and Singapura.

Therefore, the reason of monitoring of forest burned areas become much more important for environmental assessment, for example, to locate and estimate the extent of burned area, to assess the damages ecologically and economically, to check the ability of the ecosystem to regenerate after the fire, to assess the pattern or the speed of the regeneration especially for vegetation regeneration, to check the outcome of any recovery intervention, and to assess the land use or land cover change after and before the fire especially for fires that happened due to anthropogenic reason.

Remote sensing can be employed to collect all of the useful information for fire investigation. The benefits of using remote sensing are its effectiveness due to the advanced technology thus minimize the cost, especially in assessing larger areas (Corona et al., 2008). Support of remote sensing technique to post-fire management, such as burned area mapping, damage severity assessment, or post-fire vegetation monitoring is required. The integration of GPS field survey and satellite imageries is currently become one of the options for the post-fire monitoring analysis. One of the examples of the satellite imageries, Landsat, contains spectral for identifying vegetation and burned area by using several algorithms. Healthy vegetation reflects radiation in near infrared (NIR) and absorbs red light in the visible region of the spectrum, whereas, burned areas reflect more radiation in the visible and shortwave infra-red (SWIR) and absorb more radiation in the NIR (Chuvieco et al., 2002). Thus, features like forest burned areas can be depicted using specific algorithms from the spectral features that find indices.

Based on the past researches, NBR is the most popular and accurate indices to estimate fire severity classes. The Normalized Burn Ratio (NBR) is a ratio of the near-infrared and second SWIR band, it was developed by Key and Benson (2006) to identify burned areas following fire and provide a quantitative characterization of burn severity. Several authors have found NBR result on fire or burn severity has a high correlation with field-based measurements in investigated area (Epting et al., 2005; Cocke et al., 2005; Parker et al., 2015). However, Roy et al. (2006) suggests to be careful when using NBR for burn severity mapping as their studies indicated sub-optimal outcomes. NBR has proven adept and is used extensively in Landsat at assessing pattern and annual characteristic of forest disturbance and regrowth, for example, in the Northwest Forest Plan, United States (Kennedy et al., 2012) and forest in Canada (White et al., 2017) over long periods. The usage of the NBR for burn mapping at regional scale using Landsat imagery was proven scientifically the best among the traditional indices, such as NDVI, NDMI, NDWI, SAVI, EVI, and more. Therefore, the research will be using NBR and dNBR as the method to identify the fire burned area and defining its severity.

B. Methodology

1. Research Design

The case study was a part of Bengkalis Region in Riau Province, Sumatera Island. Regency. It is located in UTM (Universal Transverse Mercator) zone 47 North with WGS 1984 as projected coordinate system. The study area that includes two districts covers 234.864 hectares. The study area is located in the Pinggir and Mandau Districts, the west part of Bengkalis regency (Figure 1). The study area selected based on the fires event that happened from July to October 2019, the largest fires that happened after 2015 fires event happened. National Department of Disaster Management stated that there are 857.756 hectares of burned area in Indonesia in 2019, which Riau holds account of burned area around 75.871 hectares. The study area also the region where the palm plantation located. The private palm plantations are PT. ADEI Plantation (14.900 hectares) and PT. Murini Sam-Sam (WILMART Group, 1.200 hectares). and the public one with the area around 110.000 hectares in Pinggir District. In addition, there is some oil wells which is owned by PT Chevron Pacific Indonesia (CPI) located in Duri, Mandau District.

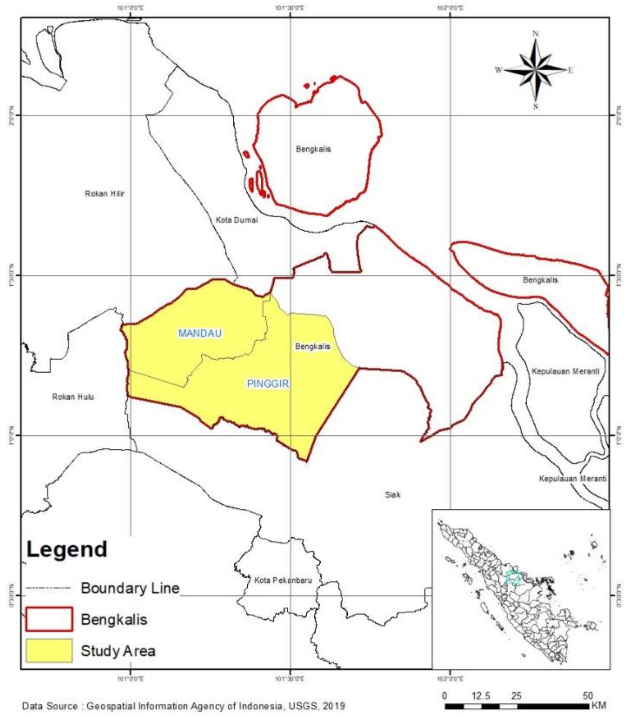

Figure 1. *The study area of forest fire in Bengkalis Region, Riau, Indonesia*

The methodology is depicted in the figure 2. The NBRI analysis and process carried through ENVI 5.2, then the validation by using confusion matrix and spatial analyst tools are executed in ArcGIS 10.5. The severity level determined by using statistical data of derived dNBR value of burned area using a method from Saputra, et al (2017).

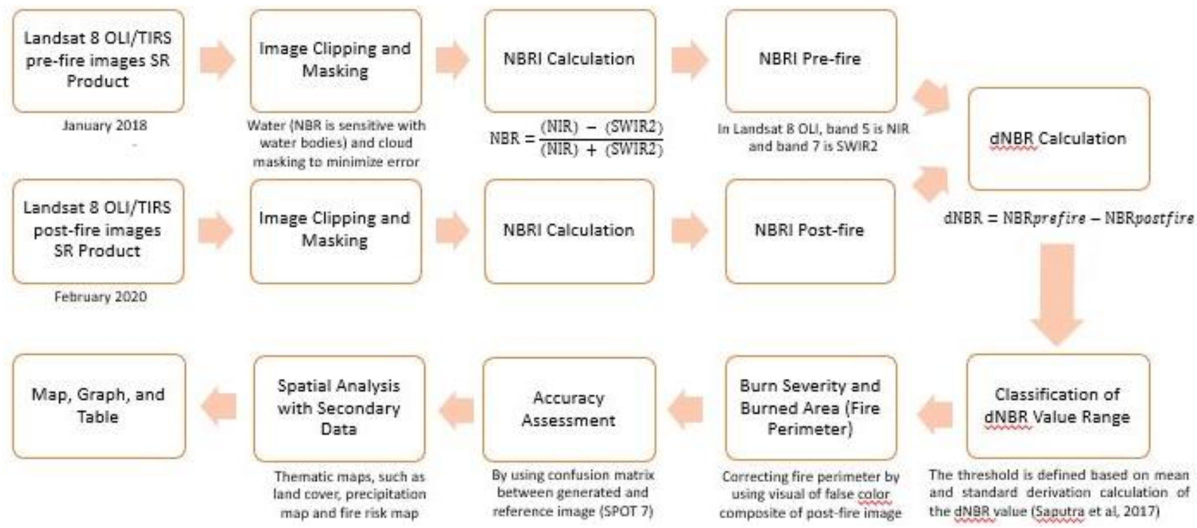

Figure 2. *Research design in this study*

2. *Instruments*

According to the objective of the study and the location of the study area, data are divided to primary and secondary data. Primary data for assessing burned area and burn severity are two Landsat 8 OLI/TIRS Path/Row 127/59 satellites imageries with different temporal or acquisition time depending on the time of the event happened, first is before fire happened and second is after fire happened. First image acquisition time for pre-fire image is on 30th January 2018 with cloud cover 15,37 %, since all the previous images before fire have cloud cover more than 25 %, the pre-fire image is taken in 2018. Also, there is no massive fires are happened in 2018, as the data of burned area is only around 51.564 hectares in entire country. Meanwhile, the second one for post-fire image is 5th February 2020 with cloud cover 23,14 %.

Data are download from EarthExplorer website that was provided by US Geological Survey (https://earthexplorer.usgs.gov/). They are free, no-fee paying, and open to public, regarding the country or the profession. Landsat which was used is level 2 Landsat that called Surface Reflectance data product with radiometric calibration and atmospheric correction already applied.

Then, the collection of secondary data is auxiliary for validation and spatial analysis purpose, such as hotspots and thematic maps. Some of them are provided by Indonesia government institutes, such as Geospatial Information Agency and National Institute of Aeronautics and Space. All of the data later was pruned according the study area. The following are gathered as auxiliary data:

1. MODIS Hotspot that can be downloaded publicly from National Institute of Aeronautics and Space of Indonesia (LAPAN).
2. Some maps of burned area in previous years (2016 and 2017) that was mapped in Riau province by National Institute of Aeronautics and Space of Indonesia (LAPAN).
3. Land cover in Bengkalis Region, Riau Province from Geospatial Information Agency of Indonesia, created in 2018
4. SPOT 7 pansharpened image obtained in March 2020 with spatial resolution 1.5 meter as a reference image
5. The map of fire risk probability level from National Institute of Aeronautics and Space (LAPAN) in Riau Provinces that created in 2017
6. The amount of the annual precipitation in the study area, provided by Geospatial Information Agency of Indonesia

Data processing and analysis was performed in these softwares: ENVI Classic 5.2, and ArcGIS 10.5.

3. *Technique of Data Analysis*

Obtaining cloud image from non-cloud image required some masking methods such as automatic masking using band threshold or manual masking in ROI, although manually masking clouds and other unwanted features can be tedious and time-consuming if such features are abundant in the scene. Region of interest (ROI) selection technique is one of the common techniques which used to obtain the desired cloud image from the actual image (Yashaskar, 2018). Aside cloud, water bodies need to masked out in burned area mapping, since it will indicate darker pixel in NBR result and wrongly identified as burned area with high severity. Failing in masking them need more effort in validation because such disturbance like cloud, snow, shadow, and water bodies can be identified as a burned area.

For calculation of NBRI, instead of creating the new formula, the feature of NDVI calculation in transformation tools in ENVI could be used because the equation between NDVI and NBRI is similar. Instead of using band for red light spectral reflectance (band 4 in OLI), band SWIR-2 (band 7 in OLI) was placed, while band NIR (band 5 in OLI) is kept. The difference between NDVI and NBRI formula is substituting Red band in NDVI algorithm to SWIR reflectance.

$$NBR\ Index = \frac{Band\ 5\ (NIR) - Band\ 7\ (SWIR2)}{Band\ 5\ (NIR) + Band\ 7\ (SWIR2)}$$ ....(Key and Benson, 2006)

The band spectral will be different depending the satellite imageries that will be used in the process, for example for Sentinel-2 the band for NIR will use band 8 and the band for SWIR2 will take band 12 or in Landsat 7 ETM+, the band for NIR is band 4 while SWIR2 band is the same as Landsat 8 OLI/TIRS. After post-fire and pre-fire NBR are obtained, calculation of dNBBR is required for investigating the severity level.

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

For accuracy assessment process, confusion matrix method will be employed using the accuracy and the error from generated (Landsat 8 OLI) and reference image (SPOT 7) using ArcGIS software from ESRI by putting evenly 75 reference points distributed across the study area, with burned area identified as number 1, and non-burned area identified as number 2. Confusion matrix method is widely accepted in accuracy assessment process, however, there might be a bias in identifying sampling area in both producer and reference image. It might develop the assumption that the validation process is less trustworthy, especially if the same user carried out these two processes of production and validation. Therefore, if it possible, fieldwork verification for ground truth checking would be the best validation method for the burned area identification.

Figure 3. *reference points and assessment process for burned area*

C. Findings and Discussion

1. *Findings*
   a. *Burned Area and Burn Severity*

Saputra et al. (2017) have developed a method to define the threshold to obtain the higher accuracy or optimum separation for the dNBR. The calculation of threshold values is conducted by calculating the average (μ) and standard deviation (σ) of each index value derived from the Landsat 8 from each field sampling points. The threshold value is defined as σ - μ, σ and σ + μ. The threshold calculation based on those formula is resulted to 0,217; 0,386; and 0,556. Those values are used to determine the range of the severity level as depicted in figure 4.

Based on the threshold calculated by average and standard deviation which resulted the burn severity, burn perimeter were corrected by using on-screen digitization on ArcGIS using post-fire false composite image (RGB 753). Based on the process, it is found that about 4,7 % of area was burned (11.014 hectares) with different level of severity (table 1), 5.402 hectares for low severity (49,04 %), 2.771 hectares (25,16 %) for moderate severity while high severity is 2.841 hectares (25,8 %).

Table 1. *Total area for each severity class based on defined threshold slicing*

Severity Class	dNBR value range	Area (ha)
Low	0,217 to 0,386	5.402
Moderate	0,387 to 0,556	2.771
High	0,557 to 0,950	2.841
Total		11.014

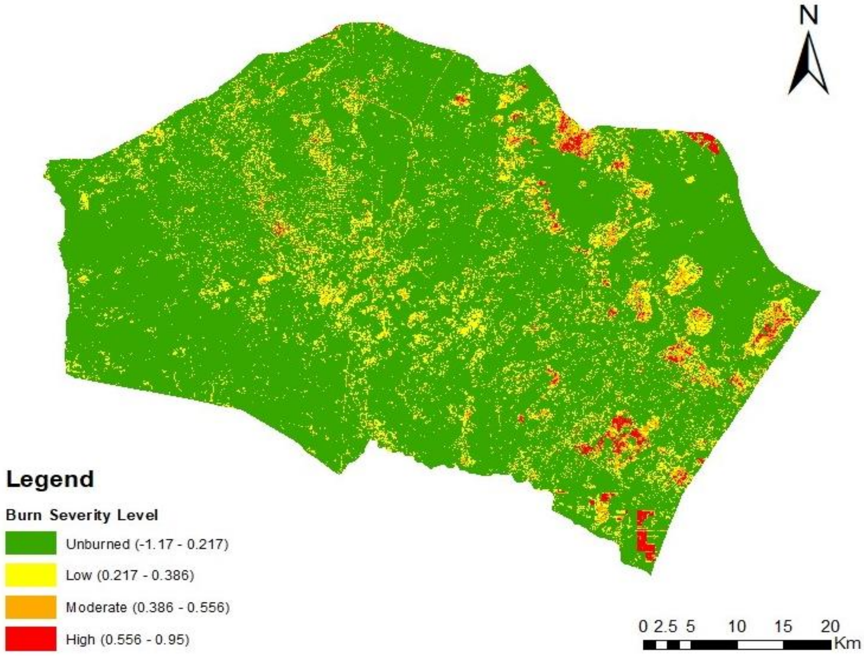

Figure 4. *Burned Severity Mapping in 2019 fires for the area of Pinggir and Mandau District, Bengkalis, Riau, Indonesia*

The study showed that the total burned area in Mandau and Pinggir District, Bengkalis Region, Riau Province affected from 2019 fires is 11.014 hectares (4,7 %) from the total of area 234.864 hectares with most of them were identified as low severity level. By overlying the spatial map of burning level with other thematic maps, the rehabilitation and recovery of the area can be planned. Prediction of the future fire risk of the study area can also be implemented. The maps of burned severity level and burned area are displayed in the figure 4 and 5.

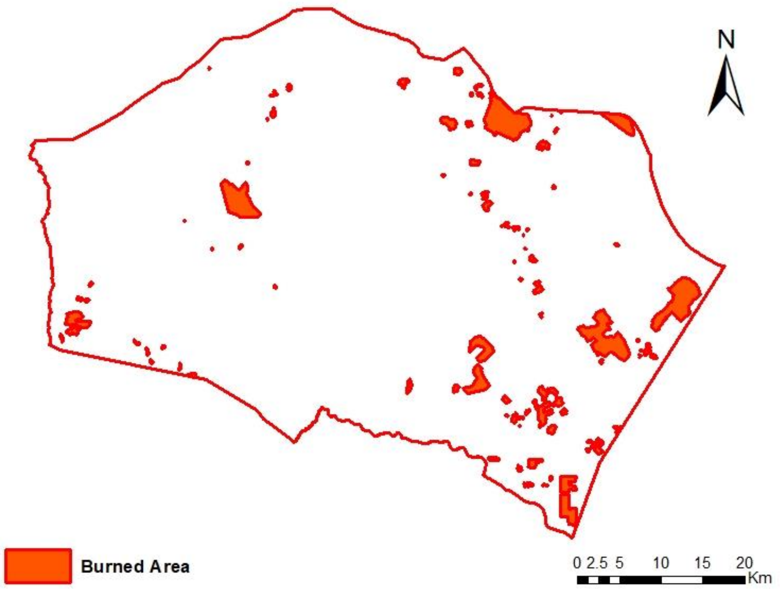

Figure 5. *Burned area identification mapping of 2019 fires for the area of Pinggir and Mandau District, Bengkalis, Riau, Indonesia*

b. Affected Land Cover

The main factor of forest fires in Indonesia is widely known as human man-made, the sporadic fire is a clue of that insight, since natural factor such as climate change and the rising of surface temperature will give a huge impact in one area. However, natural and climate factors, such as precipitation and temperature are contributing to this phenomenon also.

83,71 % of the burned area is located in the adequate rainfall intensity zone or moderate rain ranging from 2.000 to 2.500 mm per year, while 16,29 % is in low annual rainfall zone, with the annual precipitation below 2.000 mm per year. While from overlay between burned area and LAPAN fire risk probability map, the findings are 80,91 % burned area is in high-risk probability area, while 1910 % is in moderate-risk class and no burned area found in the low-risk class area. This statistic depicts that burned area in 2019 fires that identified in this study particularly happened in the adequate rainfall zone with high probability or high risk of fire.

Furthermore, based on the weighted overlay with land cover map from Geospatial Information Agency, the area with high vegetation cover is the one which damaged the most from the fire, such as grassland, plantation, shrub and heathland, as well as woodland and forest, as presented in the table 2.

Table 2. *Affected land cover in burned area*

Land cover class	Burned area (hectares)	Percentage (%)
Grassland	130,93	1,19
Oil Wells	67,10	0,61
Palm Oil Plantation	2.197,00	19,96
Residential Area	996,54	9,06
Shrub and Heathland	2.083,41	18,93
Woodland and Forest	5.529,65	50,25

Although it is rarely happened, the burned area in 2019 fires also spotted in non-vegetation cover, it is identified in oil wells and residential area. Bengkalis has many oil wells, one of them is located in Duri, Pinggir district that was owned by PT. Chevron Pacific Indonesia (CPI). However, generally the fires were happened in the vegetation cover, especially in tree-canopy cover, such as woodland and forest.

c. Accuracy Assessment

Kappa coefficient is calculated using confusion matrix to show the agreement level between the category of generated image and reference image pixel. A kappa value of nearly 1 indicates perfect agreement, while a value close to 0 represents complete randomness. The value of Kappa coefficient in this study is 0,83 and it is considered as acceptable (table 3).

Table 3. *Confusion matrix and result of statistical analysis*

	Burned area	Non-burned area	Total (user)
Burned area	45	5	50
Non-burned area	1	24	25
Total (producer)	46	29	75
Overall accuracy	92,00		
User accuracy	90,00	96,00	
Commission error	10,00	4,00	
Producer accuracy	97,83	82,76	
Omission error	2,17	17,24	
Kappa coefficient	82,69		

The value of corrected pixel based on the accuracy assessment using reference image is presented in the figure 6. All of the value of NBR post-fire index in the burned area sampling point that corrected using reference image are lower than the value of NBR pre-fire index. The figure depicted the value of dNBR in all reference points are positive, thus it indicates the sampling points are located on the burned area.

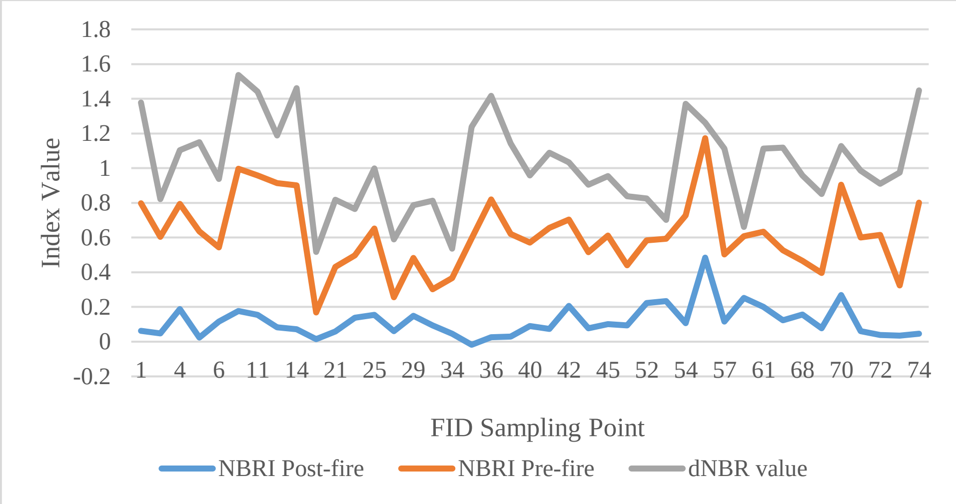

Figure 6. *Index value in sampling points which have positive value of dNBR index indicating burned area*

2. *Discussion*

Some of the burned area in the north part of study area was also burned in 2016 as well as the southwest part of the study area which was also burned in 2016 and 2017. These areas in this location were mostly used for plantation as depicted in the land cover map provided by Geospatial Information Agency. While the north part was mostly forestry area, however it was also located near the plantation. High and tall vegetation cover are the most affected area of fire as later it was found that 50,25 % of the burned area were located in forest land with rapid vegetation cover.

The fires spread sporadically as depicted in the burned area map. This could be one of characteristics of man-made fire for opening new lands, either for plantation or agricultural purpose. Natural factor such as climate change or extreme temperature usually will concentrate in one area with large coverage of fires. It might be also a combination between human factors and environmental cause that help to spread the fire initiated by human, since the peat soil, which was characteristic of Sumatra's soil, is prone to the fire so the small fire which is occurred above this type of soil can become massive.

Furthermore, the minimum precipitation or little rain intensity and the extreme surface temperature during the dry season could not put out the fire and stop its transmission. The smoke and fog from fires also hinder social and community workers as well as government people to help extinguish the fire in the affected area, and creating another problem such as respiratory and lung disease that affected the health of the people and increased number of traffic-accidents caused by visual disruption by these smoke and fogs.

By overlying them with other thematic maps, the burned area map along with burn severity level can be useful for rehabilitation and recovery planning in the area that affected by fire. These maps can be indicator of how fires will occur in the future and obtain the information of the fire history and highly risk area of fire probabilities in the future. Separation between open unburned area covered in mineral soil and high severity level of burned area can be difficult in validation process, since these two lands have a lot of similarity in visual, therefore fieldwork verification is the best way for obtaining the best result in burned area assessment.

D. Conclusion

Study shows that Landsat 8 OLI/TIRS can detect burned area through the spectral reflectance of NIR (band 5) and SWIR-2 (band 7). NBR is very sensitive to water level so masking them out is necessary to avoid misclassification in burned area. Total burned area is 11.014 hectares (4,7 % of study area) with 49 % is in low severity class, 25 % and 26 % in medium and high class respectively with Kappa coefficient of 0.83. it is considered as acceptable, however, as there might be some bias toward the visual interpretation in reference image, the fieldwork verification for ground truth checking is more appropriate in order to get the optimum result of separating burned area to non-burned area and higher accuracy of the product map. Affected land cover is mostly vegetated land (90,3 %) with high and tall tree canopy (woodland and forest) as majority of the affected land from fire (50,25 %).

Acknowledgement

The Authors would like to thank Stipendium Hungaricum program that support the study and the institution in Indonesia that provide the secondary data, Geospatial Information Agency and National Institute of Aeronautics and Space of Indonesia (LAPAN) specifically.

E. References

Chuvieco, E., Martín, M.P., & Palacios, A. (2002). Assessment of Different Spectral Indices in The Red-Near-Infrared Spectral Domain for Burned Land Discrimination. *International Journal of Remote Sensing 23,* 5103–5110. https://doi.org/10.1080/01431160210153129.

Cocke, A. E., Fulé, P. Z., & Crouse, J. E. (2005). Comparison of burn severity assessments using Differenced Normalized Burn Ratio and ground data. *International Journal of Wildland Fire 14(2),* 189-198. https://doi.org/10.1071/WF04010.

Corona, P., Lamonaca, A., & Chirici, G. (2008). Remote sensing support for post-fire forest management. *iForest 1: 6-12* [online: Feb 28, 2008] URL: http://www.sisef.it/iforest/

Epting, J., Verbyla, D., & Sorbel, B. (2005). Evaluation of remotely sensed indices for assessing burn severity in interior Alaska using Landsat TM and ETM+. *Remote Sensing Environment 96,* 328–339. https://doi.org/10.1016/j.rse.2005.03.002.

Kennedy, R.E.; Yang, Z.; Cohen, W.; Pfaff, E.; Braaten, J.; & Nelson, P. (2012). Spatial and temporal patterns of forest disturbance and regrowth within the area of the Northwest Forest Plan. *Remote Sens. Environ., 122,* 117–133.

Key, Carl H. & Benson, Nathan C. (2006). Landscape Assessment (LA) Sampling and Analysis Methods. *FIREMON: Fire Effects Monitoring and Inventory System.* Gen. Tech. Rep. RMRS-GTR-164-CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 55.

Parker, B.M.; Lewis, T.; & Srivastava, S.K. (2015). Estimation and evaluation of multi-decadal fire severity patterns using Landsat sensors. *Remote Sensing Environment*, *170*, 340–349.

Roy, D.P.; Boschetti, L.; & Trigg, S.N. (2006). Remote Sensing of Fire Severity: Assessing the Performance of the Normalized Burn Ratio. *IEEE Geoscience and Remote Sensing Letters 3*, 112–116.

Saputra, A. D., Setiabudidaya, D., Setyawan, D., Khakim, M. Y. N., & Iskandar, I. (2017). Burnscar analysis using normalized burning ratio (NBR) index during 2015 forest fire at Merang-Kepahyang peat forest, South Sumatra, Indonesia. *American Institute of Physic.* 100001-1–100001-7. https://doi.org/10.1063/1.4987107.

USAID. (2016). Forest & Land Fires Impact Study in Katingan-Kahayan Landscape. *United States Agency for International Development*. 33.

White, J.C.; Wulder, M.A.; Hermosilla, T.; Coops, N.C.; & Hobart, G.W. (2017). Remote Sensing of Environment: A nationwide annual characterization of 25 years of forest disturbance and recovery for Canada using Landsat time series. *Remote Sensing Environment 194,* 303–321.

Yashaskar, E. H. (2018). Identification and Masking Method of Clouds in Satellite Images. *Master thesis, Department of Applied Signal Processing Blekinge Institute of Technology SE–371 79 Karlskrona, Sweden.* 49.