



Forest and peatland fire severity assessment at Siak Regency, Riau Province using Sentinel-2 Imagery

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Abstract. *Siak Regency, Riau Province is one of the most forest and land fire-prone regencies in Indonesia. Most of the fires occur in peatland areas which contributes to the transboundary haze pollution in the region. Despite limited studies, fire severity assessment is an essential step in post-fire activities to estimate ecological impacts and economic impacts, and law enforcement. This study aimed to estimate fire severity using Sentinel-2 imagery at Siak Regency, Riau Province. The methods applied Normalized Burn Ratio on Sentinel-2 Imageries using Near-Infrared and Shortwave Infrared bands for 2019. The results indicated that the burned areas in Siak Regency were classified into four fire severity classes by difference Normalized Burn Ratio (dNBR). The area was classified into low fire severity (16.34%), moderate-low fire severity (4.96%), moderate-high fire severity (0.89%), and high fire severity (0.33%). The high fire severity was found mainly at Sungai Apit District.*

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INTRODUCTION

Riau province is a peatland-dominated area in Indonesia covering 3.87 million ha, the largest in Sumatera. Approximately 2.31 million hectares of the peatland area have been degraded due to fires, water mismanagement, and mining activities (Masganti *et al.*, 2014). The peatland fire always occurs annually and contributes to the region's transboundary haze pollution, closely related to an acute respiratory infection problem experienced by the community in some areas of the province (Syaufina and Hamzah, 2021). In 2019, the burned area in Riau Province covered 90 550.00 ha (KLHK, 2019). Siak Regency, as one of the regencies in Riau Province, has been one contributor to the fire problem as it contributes 12.5% of the peatland area in the province.

The magnitude of the impact of fire on ecosystem elements and the environment depends on several factors: fire intensity, fire severity, soil type, rain that falls after the fire, and the extent of the fire (Syaufina and Ainuddin, 2011). One approach to identifying fires' impacts is the fire severity assessment, which measures the impacts of fires on vegetation and soil properties. This approach can be used for forest fire impact assessment as one of the activities in forest fire control. Forestry Law no. 41 of 1999 and Government Regulation Number 45 of 2004 on Forest Protection-Article 22, Article 23, Article 24, and Article 25 describe

the importance of implementing forest fire control programs, including prevention, suppression, and post-fire management (Syaufina, 2017). Fire severity assessment in Indonesia seems to be limited in the implementation with several challenges.

Various fire severity assessment has been developed using field-level assessment and satellite data or spatial data approach. Assessing the impact of forest and land fires directly on the field is often constrained by places that are time-consuming and difficult to reach, therefore, the application of technology in assessing the impact of land fires needs to be further developed. Monitoring an area is now very easy and fast with the rapid development of technology every year because many tools and methods have been used, including remote sensing using satellite assistance (Que *et al.*, 2019). The use of technology in assessing the impact of the fire is expected to produce accurate and compelling data to assess the impact of forest and land fires. Spatial analysis in forest and land fire research has been widely used, among others, to determine the classification of burned area, estimate the burned area, the impact of fires on land cover change, carbon emissions, peatland fire prediction, and haze trajectory (Maulana *et al.*, 2019; Tantriawan *et al.*, 2018; Hafni *et al.*, 2018; Sitanggang *et al.*, 2017; Thariqa *et al.*, 2016).

Moreover, identification of burned areas can be approached by ground checking and hotspot analyses as a fire indicator. A hotspot is a term for a pixel with a temperature value above a certain threshold from the interpretation of satellite imagery, which can be used to indicate forest and land fires (KLHK, 2016). Hotspots are usually used as an indicator of the forest, and land fires in an area, an area with more hotspots, indicates a higher chance for forest and land fire to occur (Endrawati, 2016). However, not all hotspots are a strong indicator of forest and land fires. The incidence of hotspots in a sequence of at least three days in an adjacent location can strongly indicate land and forest fires occurrences (Syaufina and Sitanggang, 2018). Therefore, a clustered hotspot is probably valuable for verifying burned areas in spatial analyses. However, spatial analysis for fire impact assessment is still limited. This study aimed to estimate the severity of forest and peatland fires using the Difference Normalized Burn Ratio (dNBR) method on Sentinel-2 imagery at Siak Regency, Riau Province.

METHODS

Study Area and Period

This research was conducted from May to September 2021 in the study area of Siak Regency, Riau Province (Figure 1). Analysis and processing of image data were carried out at the Forest and Land Fire Laboratory, Faculty of Forestry and Environment, IPB University.

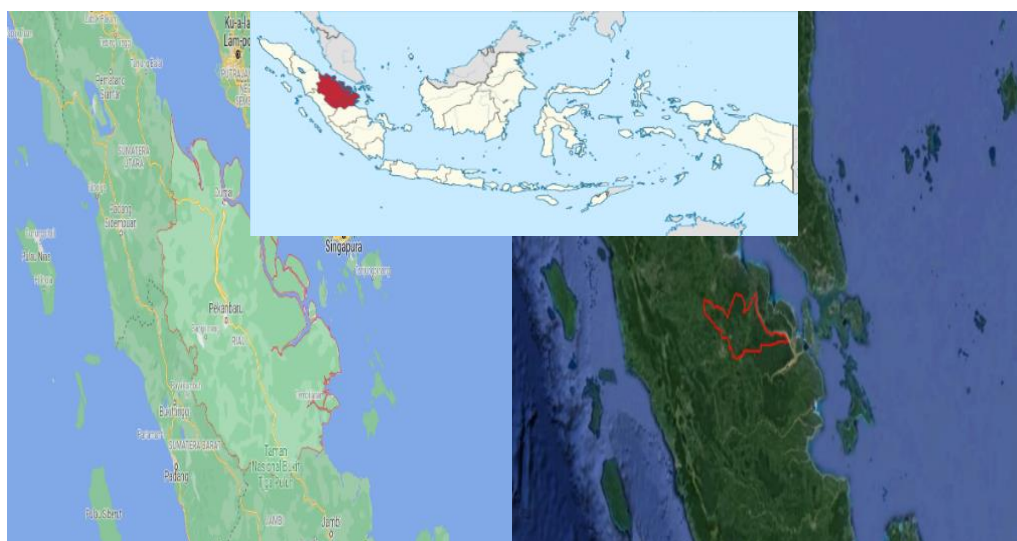


Figure 1 The study area of Siak Regency, Riau Province, Indonesia

Siak Regency is a regency in Riau Province, covering 8 556.09 km² with a population of 457 940 distributed in fourteen districts. It is located between 1°16'30"-00°20'49" South and 100°54'21"-102°10'59" East, as a growth triangle of Indonesia-Malaysia-Singapura. The most landscape of Siak consists of lowland in the eastern part and highland in the western part, dominated by peatland area covering 484 260 ha or about 56.6% of the total area. It is included in a tropical region with an average temperature of 25-32°C and high relative humidity and rainfall. Forest area covers 23.1%, and plantation area covers 20.9% of the total area of Siak Regency. As peatland-dominated areas, forest and land fires have become common phenomena that occur annually in Siak, particularly in dry seasons. The study was focused on operational working area of Manggala Agni (DAOPS) Siak.

Data Collection

Hotspot Data

Hotspot data was used in this study to identify the image of the before burning period (Pre fire) and image after the burning period (Post-fire). Besides, the data was used as forest and land fires indicator for fire occurrences analyses. The hotspot data was derived from the LAPAN MODIS catalog of Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery and Suomi National Polar-orbiting Partnership (SNPP) satellite for 2019. The confidence level shows that the hotspot monitored from remote sensing satellite data is genuinely an actual fire incident in the field (LAPAN, 2016). In this study, the confidence value used is >80% (Table 1). The following are the confidence interval criteria according to Giglio *et al.*, 2018):

Table 1 Confidence level of hotspot criteria

Percentage Range	Confidence Level
0%≤C<30%	Low
30%≤C<80%	Nominal
80%≤C≤100%	High

Where: C: confidence level

Sentinel-2 Images

The image used in this study is Sentinel-2 which is open-access imagery with higher spatial resolution than other infrared images. The Satellite imagery was downloaded from Copernicus Open Access Hub based on the results of hotspot data processing. We used satellite images of April 2019 for the Pre fire period and September 2019 for the Post-fire period.

Data Analysis

Normalized Burn Ratio (NBR) Calculation

The Normalized Burn Ratio (NBR) is designed to highlight burned areas and estimate fire severity (Que *et al.*, 2019). The application of this method requires satellite image data before the forest and land fire and after the area burned (Saputra *et al.*, 2017). Here is the equation to calculate the NBR:

$$NBR = \frac{NIR - SWIR}{NIR + SWIR}$$

Description:

NBR : Normalized Burn Ratio

NIR : Near-Infrared Spectral Band Value

SWIR: Short Wavelength Spectral Band Value

The image used in this study is Sentinel-2. Near-Infrared (NIR) uses band 8A, and Shortwave Infrared (SWIR) uses band 12 (Table 2). NIR represents vegetation conditions, while SWIR is used for burned areas. The following is the equation for calculating NBR based on the United States Geological Survey (USGS):

$$NBR = \frac{8A - 12}{8A + 12}$$

Table 2 Applications of each band in Sentinel-2 image

Band	Spectral Range	Wavelength (µm)	Spatial Resolution (m)
1	Aerosol	0.443	60
2	Blue	0.490	10
3	Green	0.560	10
4	Red	0.665	10
5	Red Edge 1	0.705	20
6	Red Edge 2	0.740	20
7	Red Edge 3	0.783	20
8	NIR	0.842	10
8A	Red Edge 4	0.865	20
9	Water vapour	0.945	60
10	SWIR Cirrus	1.357	60
11	SWIR _S	1.610	20
12	SWIR _L	2.190	20

Difference Normalized Burn Ratio (dNBR) Calculation

The value of Difference Normalized Burn Ratio (dNBR) is the comparison result of the Pre fire and the Post-fire normalized burn ratio calculation. The dNBR value is then used to find the value of the severity of forest and land fires (Table 3). The higher the dNBR value, the higher the severity of the fire that occurs. On the contrary, if the resulting dNBR value is low, then the severity is low. The following is the equation for calculating dNBR based on the United States Geological Survey (USGS):

$$\Delta NBR = \text{Pre fire NBR} - \text{Post fire NBR}$$

Table 3 Fire severity criteria

Value	Description
0.1	Unburned
0.27	Low severity
0.44	Moderate-Low Severity
0.66	Moderate-High Severity
1.3	High Severity

RESULTS AND DISCUSSION

Hotspot Distribution

Hotspot data were used in this study to identify the fire period for determining the Pre fire and Post-fire images. The image selection was conducted by identifying the highest hotspot period as a reference for the fires occurrences. The analysis indicates that Siak Regency experienced two fire seasons, namely February-March and July-September. The highest hotspot was found in August (Figure 2) when the VIIRS sensor satellite image (SNPP satellite) recorded 767 hotspots, and the MODIS sensor satellite image recorded 104

hotspots. In Siak, 104 000 hectares were burned between 2003 and 2019, and 91% or about 95 000 hectares were burned consistently in February-March and June-August. Most fires occurred in scrubland and bareland, 54% of fire hotspots from 2003 to 2019 in Siak occurred within lands considered unmanaged (Hapsari *et al.*, 2020).

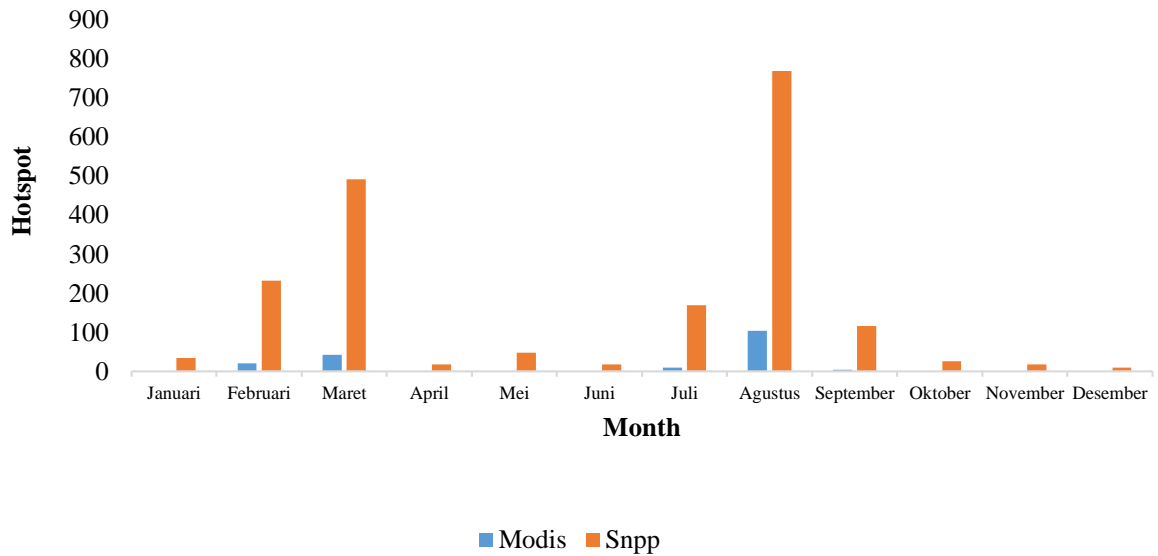


Figure 2 Monthly hotspot distribution of Siak Regency in 2019

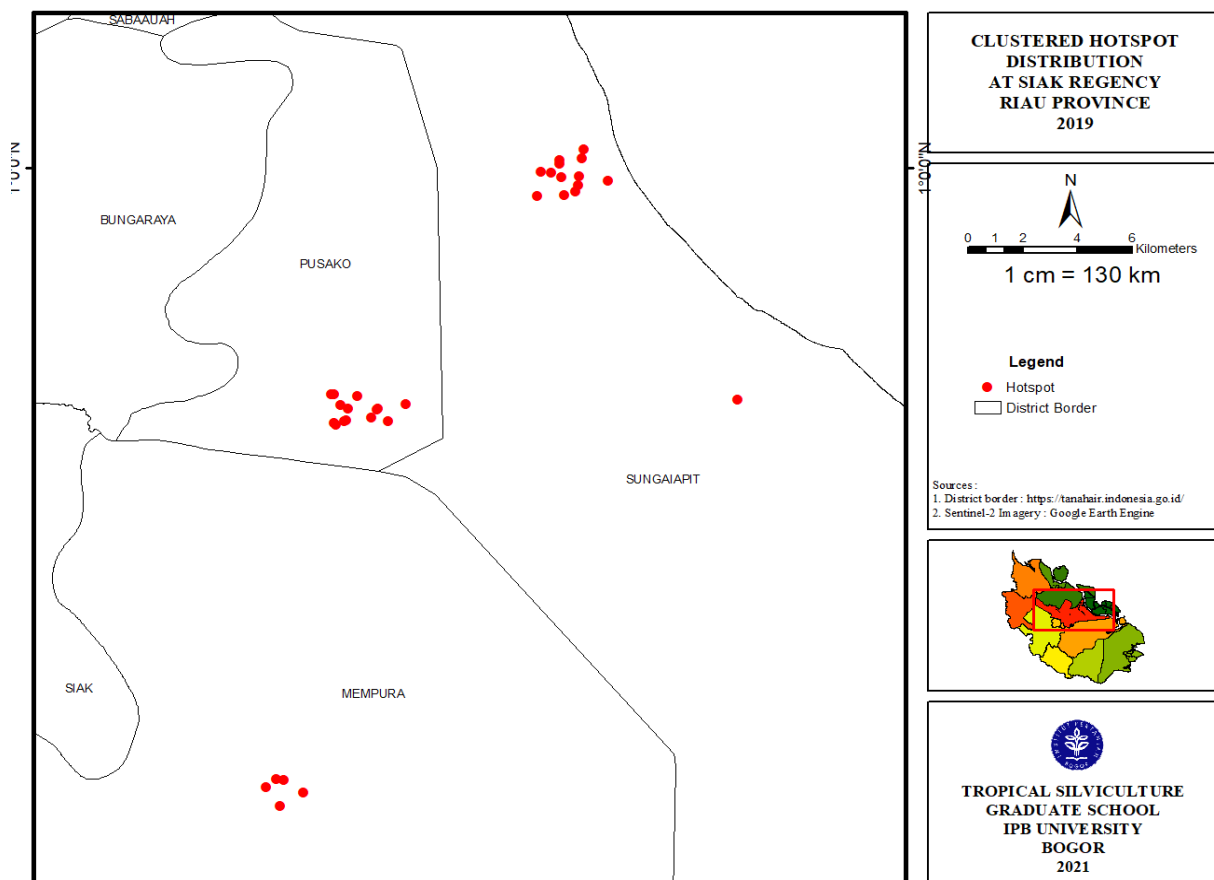


Figure 3 Clustered hotspot distribution at Siak Regency

The confidence interval used is >80%, whereas the higher the confidence interval is, the higher the potential that the hotspot is an actual land or forest fire (LAPAN, 2016). In addition to using confidence intervals, the estimation of forest and land fires can be analyzed from hotspots clustering. A large fire is not commonly detected as only one hotspot as the heat radiation, and convection effect spreads to the surroundings. Therefore, the hotspot cluster is likely to be ascertained that land and forest fires occurred (LAPAN, 2016); information on the number of hotspots in estimating the burned area should use sequential data of hotspot detected for a minimum of 3 to 7 days during the fire period. Recent studies identify that clustered and sequential hotspots are a strong indicator for forest and land fire occurrences (Rezainy *et al.*, 2020; Syaufina and Sitanggang, 2018; Kirana *et al.*, 2015). Our spatial analyses show clustered hotspots as a strong indicator for forest and land fires occurrences (Figure 3).

Forest and Land Fire Severity

The Normalized Burn Ratio (NBR) value is used to identify the burned area. NBR calculation uses Near Infrared (NIR) wavelength, whereas Sentinel-2 imagery uses band 8A, and Shortwave Infrared (SWIR) uses band 12. Normalized Burn Ratio (NBR) calculation requires Prefire images and Post-fire images. Determination of the image before and after the forest and land fire can use the distribution of hotspots to indicate the occurrence of a land fire. Based on the Sentinel-2 RGB image composite (12, 8A, 4), the image's colour changes can be seen before and after the fire (Figure 4). Image composite is a process that combines three bands in the image to get red, green and blue colours. The results obtained showed a change in the colour hue in the image after the fire. The NBR was better used to extract burned area rather than NDVI or a single spectral band (Prasasti and Triyono, 2020). According to Hafni *et al.* (2018), the burned area is visually indicated by: (1) reddish-brown colour, and the colour is darker than that of the surrounding area; (2) the shape of the burned area is generally a rectangular polygon; (3) the size of the burned area ranges from 0.87-216.49 ha; (4) the pattern is irregular; (5) the texture is smooth; (6) the location of the burned area is generally land cover in the form of shrubs, oil palm plantations, plantation forests, and secondary forests; (7) associated with the presence of roads and canals.

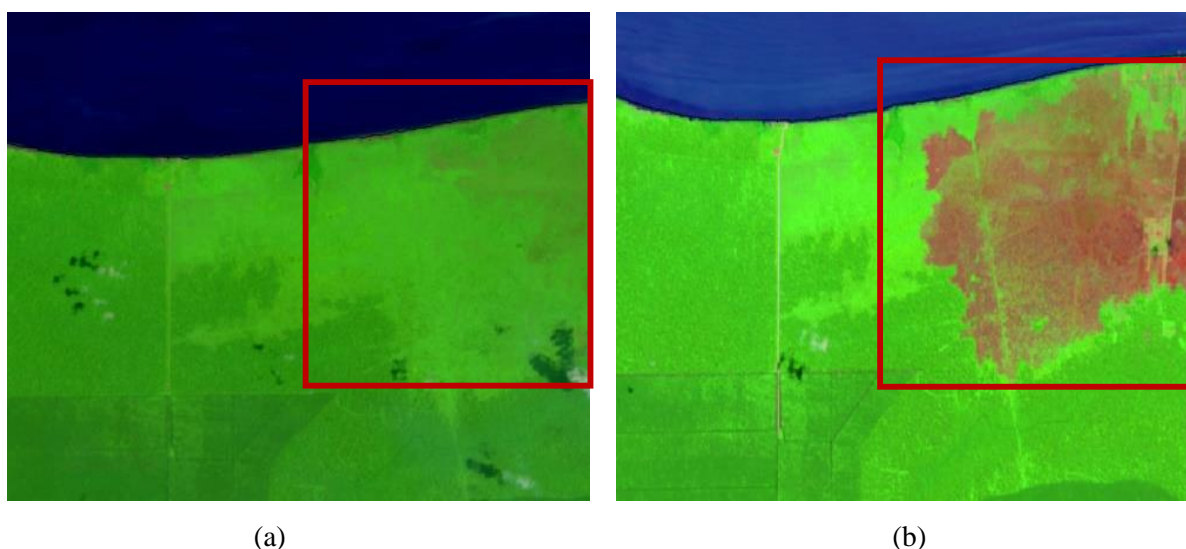


Figure 4 Image of Sentinel-2 RGB composite (12, 8A, 4) in Siak Regency in 2019
(a) Pre fire image, (b) Post-fire image

Different studies suggested that the NBRb12 (short-wave infrared 2–SWIR2) produced the best results for detecting burnt areas. SAM resulted in a 73% overall accuracy in thematic mapping, and Sentinel-2 can be used to discern burned areas and burning severity (Amos *et al.*, 2019). Predictive local thresholds of dNBR values showed slightly higher classification accuracy for Sentinel 2A (73.33%) than Landsat-8 OLI (71.11%),

suggesting the adequacy of Sentinel 2A for forest fire severity assessment and mapping in Mediterranean pine ecosystems (Mallinis *et al.*, 2018). Fire severity can be mapped with very high accuracy using Sentinel 2 imagery, and RF supervised classification. The mean accuracy was >95% for the unburnt and extreme severity class (total crown consumption), >85% for high severity class (full crown scorch), >80% for low severity (burnt understory, unburnt canopy) and >70% for the moderate severity class (partial canopy scorch) (Gibson *et al.*, 2020). Higher canopy cover and higher topographic complexity were associated with a higher rate of under-prediction due to the limitations of optical sensors in viewing the burnt understory of low severity classes under these conditions (Gibson *et al.*, 2020). The area burned estimated using the Sentinel 2A data is more accurate, which can be justified by the higher spatial resolution of this data (Teodoro and Amaral, 2019). Nevertheless, the optimal spectral index for quantifying fire severity varies with forest type. Still, there is scope to group forests by structure and fire-regeneration strategy to simplify fire-severity classification in heterogeneous forest landscapes (Tran *et al.*, 2018). Besides, Recovery rates were generally most excellent for several years following the fire. Recovery in terms of percent NBR was often more significant for higher-severity patches. Recovery rates varied between forest types, with conifer-oak-chaparral showing the most excellent NBR recovery rates, mixed conifer showing intermediate rates, and ponderosa pine showing the slowest rates (Bright *et al.*, 2019).

The Difference Normalized Burn Ratio (dNBR) value is used to estimate the forest and land fires severity. A high dNBR value indicates severe damage, and a low dNBR value indicates a high vegetation growth rate after the area is burned. Calculation of dNBR is the difference in value between the Pre fire NBR with the Post-fire NBR. Fire severity in resprouter open forests and woodlands was most accurately mapped using the delta Normalised Burnt ratio (dNBR) (Tran *et al.*, 2018). The analyses resulted in four fire severity classes in Siak Regency Low severity, moderate-low severity, moderate-high severity, and high severity. Forest and land fire in Siak is dominated by low fire severity area (79 106 ha), followed by moderate-low severity area (24 036 ha), moderate-high severity area (4 319 ha), high severity area (1 613 ha), and unburned area (375 191 ha) (Table 4).

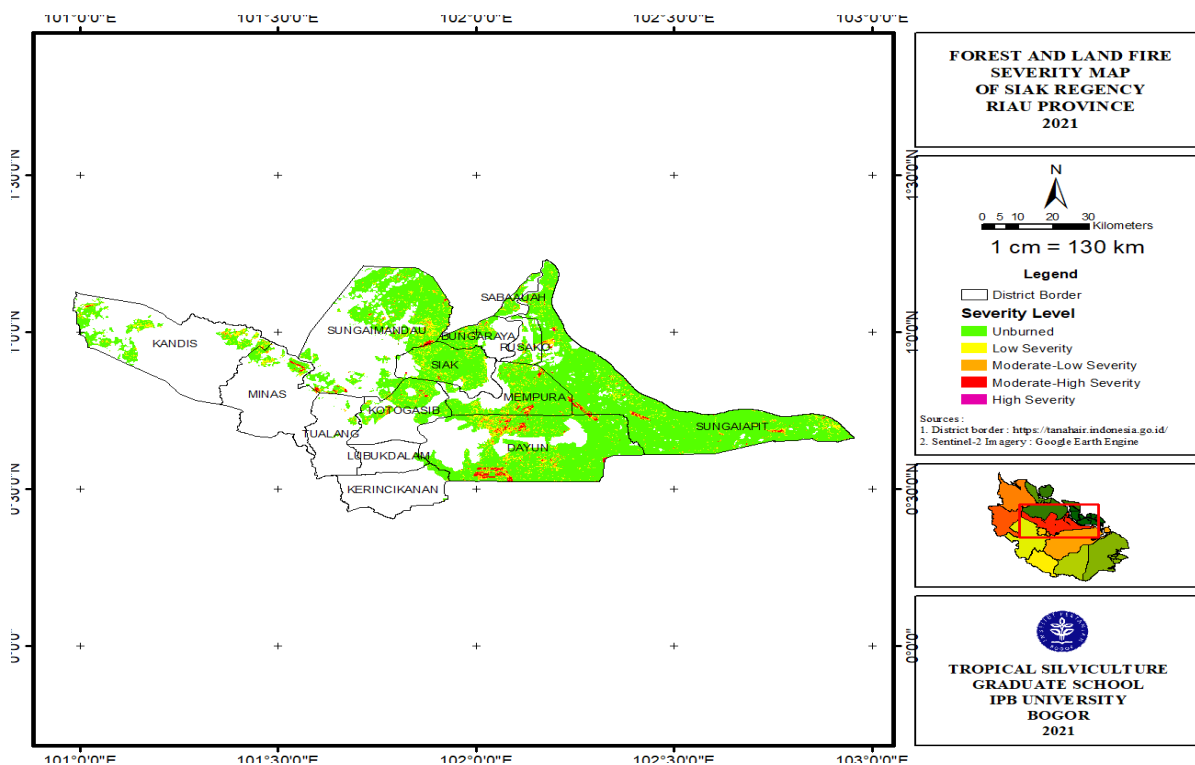


Figure 5 Map of the severity of peatland fires in Siak Regency, Riau Province in 2019

Spatial distribution of the forest and land fire severity on peatland area at Siak Regency, Riau Province is characterized in various colours. Low severity is yellow, moderate-low severity is orange, moderate-high severity is red, high severity is purple, and the unburned area is green (Figure 5). The burned area mainly was found at Sungai Apit and Mempura Districts, as found by other studies (Nurjanah and Sakir, 2021; Widodo *et al.*, 2018). Moreover, Siak Regency has 13 Disaster-prone Districts and 71 Disaster-prone Villages. Districts that are prone to disasters include Siak, Sungai Apit, Minas, Kandis, Lubuh Dalam, Kerinci Kanan, Koto Gasib, Tualang, Sungai Mandau, Dayun, Bungraya, Mempura, Sabak Auh, Pusako districts. The most considerable contribution to disaster-prone villages is in the Sungai Apit District, which consists of 14 disaster-prone villages (Nurjanah and Sakir, 2021). Forest fire in peatland areas is mainly contributed by dry peat condition, which is influenced by groundwater table condition (Widodo *et al.*, 2019). Peat fires on community land occur primarily during the dry season. The burning of peatland is generally a practice used for land clearing. So-called slash-and-burn practices for land clearing is preferred because it is cheap, and the leftover ash serves as a fertilizer for the peat soil (Wasis *et al.*, 2019).

Table 4 Forest and land fire severity classification at Siak Regency in 2019

Fire Severity Classes/Condition	Area (ha)	Percentage (%)
Unburned	375 191.63	77.34
Low severity	79 106.00	16.34
Moderate-Low Severity	24 036.00	4.96
Moderate-High Severity	4 319.00	0.89
High Severity	1 613.00	0.33

CONCLUSION

Siak Regency has two fire seasons, namely February-March and July-September, with the peak in August. Clustering hotspots can be used as solid indicators for fire occurrences. The spatial analyses using *Normalized Burn Ratio on Sentinel-2 Imageries using Near-Infrared and Shortwave Infrared bands* are appropriate for peatland fire severity classification. The analyses showed that peatland fire in Siak Regency was classified into four classes of fire severity, which was dominated by the low fire severity (16.34%), followed by moderate to low severity (4.96%), moderate to high severity (0.89%) and high fire severity (0.33%). The majority of fire occurred in Sungai Apit and Mempura Districts with high severity class found in Sungai Apit District.

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