Regular Research Article

Forest and Peatland Fire Dynamics in South Sumatra Province

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Abstract: South Sumatra Province experiences forest and land fires every year. Peatland and human activity have caused this region to be more vulnerable to fire. In this study, we used annual mapping to describe the history of forest and land fires in Ogan Komering Ilir (OKI) District of South Sumatra to analyze fire trends during the 2015-2019 period. Hotspot data were obtained from Terra/Aqua MODIS satellite imagery at all confidence levels. Burned areas were identified using the Normalized Burn Ratio (NBR) Index, with data sources from Landsat 8 satellite imagery obtained from the USGS (United States Geological Survey). The highest number of hotspots were detected in 2015 (33,748), with 72% was located on peatland. Historical analysis of hotspot numbers, shows that the majority of burning occurs in September and October. This indicates that prevention activities must be carried out more intensively before these months. Linear regression between annual hotspot numbers and rainfall was not significant. Hotspots indicative of forest and land fire in OKI District were more influenced by human activities. The largest burned area (993,999 ha) occurred in 2015. The 2015 El Niño event triggered drought and worsened forest and land fires in Indonesia. Although no El- Niño conditions occurred in 2016-2018, fires continued to occur in OKI District, showing their independence from extreme drought. The fires occurring on peatlands burned a large area during 2015-2019 indicating that forest and land fires management must become a top priority in OKI District.

Keywords: Burned area; Hotspot numbers; Peatland fires; South Sumatra; Ogan Komering Ilir; Rainfall.

1. Introduction

Forest and land fires occur almost every year in Indonesia. Indonesia experienced the most severe fires in the world during the El Niño phenomenon of 1997/1998 with a burned area of 11,698,379 hectares, approximately 624,000 hectares of which occurred in the Sumatran peat swamps (Tacconi, 2003; Bappenas-ADB, 1999). The air pollution from dense haze that year came mostly from forest and peatland fires. Another major El-Niño event occurred in 2015, resulting in the biggest fires of the last decade. Climate and weather determine the length and severity of the fire season (Chandler et al., 1983). Total burned area in 2015 was 2.61 million hectares, approximately 33 % of which occurred on peatland, with 67 % occurring on mineral soils (MoEF, 2016). In 2019, more severe fires burned approximately 1.64 million hectares (MoEF 2020). The history of forest fires in Indonesia clearly shows that fires are regularly burning in peatland areas, not only on mineral soils. Peatland fires cause more severe environmental impacts than those on mineral soils. Smoke sampling, conducted in Central Kalimantan Province, recorded that there are more than 90 gases produced from peat fires, including greenhouse gases and other gases harmful to human health (Stockwell et al., 2016). Haze from peat fires can cause transboundary haze pollution. Forest and peatland fires in 2015 caused such haze to spread to neighboring countries including Malaysia, Singapore and a portion of Thailand (MoEF, 2015). This affected the relationships between Indonesia and neighboring countries.

Indonesia has the fourth largest area of peat in the world after Canada, Russia and the United States (Maltby & Immirzi, 1993). The peatland area in Indonesia is approximately 14,905,575 hectares spread across Sumatra 43.18 %, Kalimantan 32.06 % and Papua 24.76 % (BBSDLP 2011). However, in the last few decades, the peatland areas in Indonesia have increasingly come under threat. Peatlands are converted for many purposes, including agricultural land, plantations, forestry,

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and settlements, all of which cause the peatlands become degraded (Wahyunto. et al., 2013). Naturally, peat is usually saturated with water. However, if peatlands are degraded due to forest clearing or drainage, water is lost from the system and the near-surface peat becomes dry (Taufik et al., 2015; Turetsky et al., 2015). Once drained, subsidence can compact the peat, leading to irreversible drying, increased flammability and low pH (Andriesse ,1988).

Indigenous peoples have influenced the occurrence of surface fires in forests and other lands for a very long time (Conrad, 2009). However, peatlands do not naturally experience subsurface burning within the peat when influenced only by weather and fuel factors. Human activities have been the trigger igniting the vast majority of peatland fires (Cattau et al., 2016; Page & Hooijer, 2012). Once ignited in the drained peatlands, subsurface fires, burning within the peat, are not influenced by wind, so the direction of spread is uncertain, making it is difficult to determine where the burning will actually occur (Saharjo et al., 2017). Peat has an extremely important role in global climate change. Forest and peatland fires increase greenhouse gas emissions released into the air which contribute to global climate change (Masganti et al, 2014). The monetary losses from the 2015 fires were estimated at USD 16.1 billion (World Bank 2016).

South Sumatra Province has the second largest area of peat (1.48 million ha) on the island of Sumatra after Riau (Wahyunto & Haryanto 2005). South Sumatra experienced the most fires of any province in 2015, with a total burned area of 646,298 hectares (Trinimalingrum et al., 2015), and another 336,798 hectares in 2019 (MoEF, 2020). Consequently, the Indonesian government has designated South Sumatra as one of provinces prone to fires (MoEF 2015). South Sumatra consists of 13 regencies; however, Ogan Komering Ilir (OKI) is a District which burns every year. In 2015 and 2019, human activities in OKI District caused extensive peatland areas to burn more severely than in other Districts. However, information regarding the historical trends of forest and land fires, especially on peatlands in Oki District, is still limited. The objectives of this study were to: (1) analyze the trends of hotspots and their dynamics during the 2015-2019 period; (2) analyze the relationship between hotspots and rainfall; (3) obtain the extent of fires, especially on peatlands; (4) analyze the relationship between hotspots and burned area. The results of this study can be used as baseline information to determine better strategies for preventing forest and land fires in OKI District.

2. Materials and Methods

2.1 Study Area

The study was conducted in OKI District (Figure 1). OKI District has an average elevation of 10 meters above sea level and is located between 2°30' north latitude and 4°15' south latitude, 104°20' and 106°00' east longitude and covers 19,023.47 km^2. OKI District has a tropical climate. The dry season is typically from May to October every year, and rainy season is from October to April. Exceptional droughts can extend dry season conditions longer than usual. Average annual rainfall was 2,522 mm during the period of analysis. Agriculture is the main sector activity in OKI District, providing significant contribution to the economic income of the region (BPS Statistic of Ogan Komering Ilir, 2018).

2.2 Data and Source

In this study, hotspot data were obtained at all confidence levels from both Terra and Aqua MODIS active fire products, downloaded from NASA (https://firms.modaps.eosdis.nasa.gov/download/). The Normalized Burn Ratio (NBR) was used to map burned areas in Landsat imagery. The top of atmospheric reflectance values from two Landsat 8 bands (Near Infrared and Shortwave Infrared) were used to derive the NBR index. The images were downloaded from the Centre for Technology and Remote Sensing Data LAPAN and the United States Geological Survey. The dataset covered the entire OKI District area from 2015 to 2019. Table 1 summarizes all data sources used in this study.
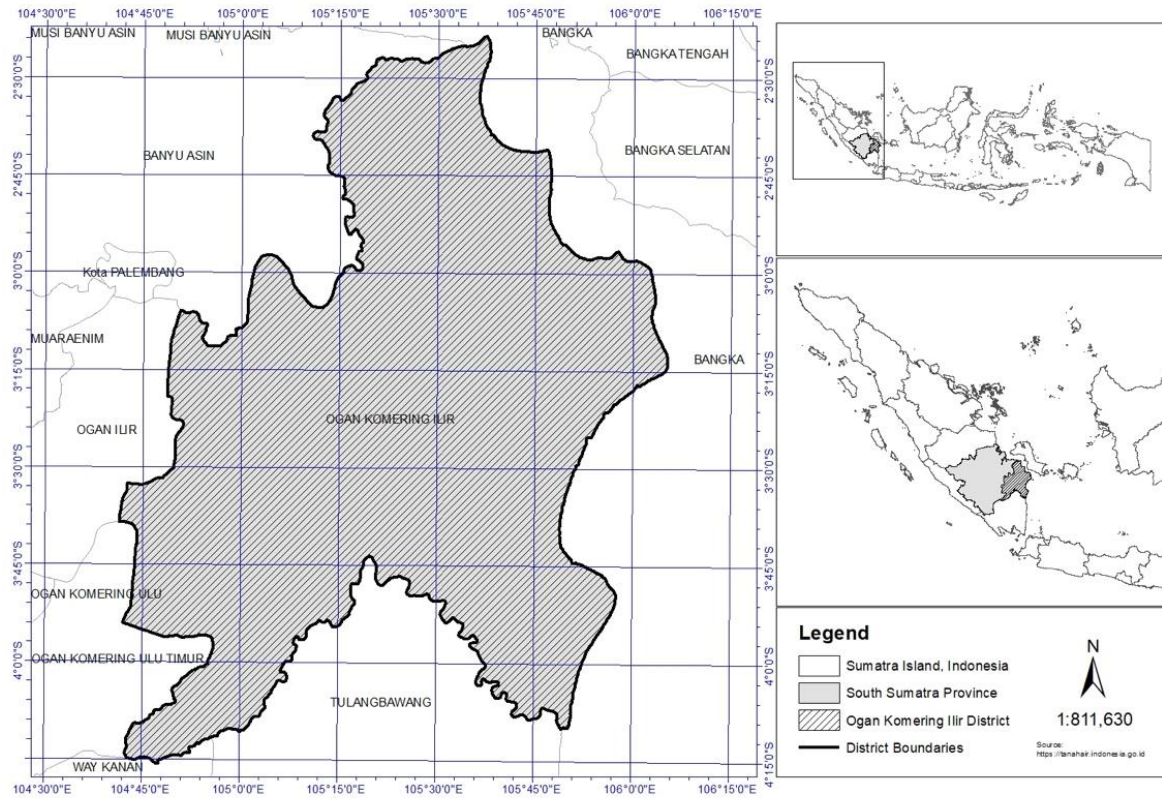
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Figure 1. Location of the study area, Ogan Komering Ilir District, South Sumatra

Daily rainfall data from 2015 to 2019 were used to investigate the relationship with hotspots. The datasets were downloaded from the National Agency of Meteorology, Climatology, and Geophysics (BMKG) at https://dataonline.bmkg.go.id/home.

Table 1. Data sources and selection to map the burned areas from 2015-2019

Data Source	Path Row	2015	2016	2017	2018	2019
Landsat Imagery (Pre-Fire)	123062	Jan-Jun	Jan-Jun	Jan-Jul	Jan-Jul	Jan-Sep
	123063	Jan-Jun	Jan-Jun	Jan-Jul	Jan-Jul	Jan-Sep
	124062	Jan-Jun	Jan-Jun	Jan-Jul	Jan-Jul	Jan-Sep
	124063	Jan-Jun	Jan-Jun	Jan-Jul	Jan-Jul	Jan-Sep
Landsat Imagery (Post-Fire)	123062	Jul-Nov	Jul-Oct	Aug-Oct	Aug-Oct	Oct-Dec
	123063	Jul-Nov	Jul-Oct	Aug-Oct	Aug-Oct	Oct-Dec
	124062	Jul-Nov	Jul-Oct	Aug-Oct	Aug-Oct	Oct-Dec
	124063	Jul-Nov	Jul-Oct	Aug-Oct	Aug-Oct	Oct-Dec
Hotspot	NASA FIRMS					

2.3 Burned Area Analysis

The Normalized Burn Ratio (NBR) Index was used to identify burned areas in major fire zones. The equation incorporates both the near infrared (NIR) and shortwave infrared radiation (SWIR) bands. Healthy vegetation exhibits a high level of reflection in the NIR and a low level of reflection in the SWIR, opposite of what is observed in areas affected by fire. The burned areas have a low reflectance in the near-infrared band and a high reflectance in the SWIR band. NBR makes use of the ratio between the NIR and SWIR bands to exploit the large spectral differences. A positive NBR value indicates healthy vegetation, whereas a negative value indicates bare land or areas that have recently burned. Typically, in unburned areas the difference in NBR values between two time periods is close to zero (García & Caselles., 1991). The following formula was used to calculate the NBR index.

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

Where:

NBR : *Normalized Burn Ratio*

NIR : *Near Infrared*

SWIR : *Shortwave Infrared*

In this study, Linear Regression Analysis was used to analyze the relationship between annual rainfall and annual hotspot numbers and also the relationship between annual hotspot numbers and annual burned area. This analysis was based on the functional or causal relationship between one independent variable and one dependent variable. The implementation steps of this study are shown in Figure 2.
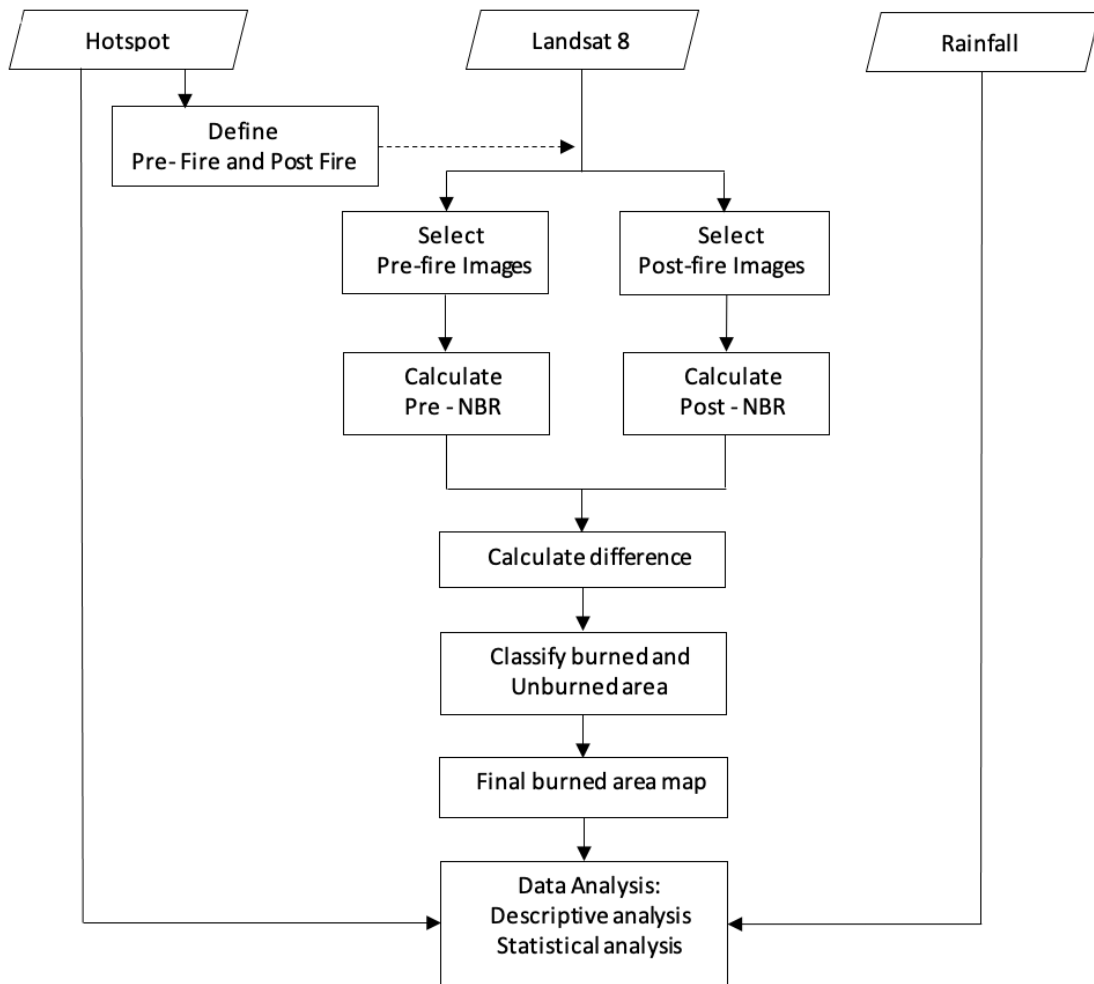

Figure 2. Flow Chart of Study Implementation

3. Results and Discussion

3.1 The number of hotspots and rainfall in the period of 2015 – 2019

Hotspots are remotely sensed indicators of forest and land fires that have higher temperatures, above a certain threshold (P.8/MENLHK/SETJEN/KUM.1/3/2018). Although hotspots do not necessarily mean fires, they can be used to identify forest and land fires at early stages (Endrawati, 2016). The number of hotspots during this period in OKI District fluctuated widely between years. Based on MODIS data from the Terra/Aqua satellites (Table 2), the highest hotspot number (33,748) was found in 2015 with 24,362 hotspots (72%) located on peatland. In 2016, hotspot numbers decreased to a mere 308 hotspots, with 84 hotspots (27%) located on peatland. In 2017, the number of hotspots increased slightly to 475 hotspots, however, in 2018, hotspots increased rapidly to

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2,592, with 704 hotspots (27%) on peatland. Serious levels of burning returned in 2019, with the number of hotspots increasing substantially to 30,630, with 14,308 hotspots (47%) on peatland.

Table 2. Annual hotspot number at OKI District in the period of 2015-2019

Years	Hotspot Number	
	Peat	Mineral Soil
2015	24,362	9,386
2016	84	224
2017	148	327
2018	704	1,888
2019	14,308	16,322

OKI District has the largest peat area (768,501 ha) in South Sumatra Province (Wahyunto et al., 2005). The peat is a wetland ecosystem that naturally stores a large amount of carbon (Hooijer et al., 2006; Joosten, 2009; Whelan, 1995) and provides an important source of livelihoods for local communities. The high levels of human activity on peatlands can be a threat to the sustainability of these ecosystems since fire is often used to manage the land after drainage, increasing the vulnerability to subsurface peat fires (Nurhayati et al. 2020). The data clearly show that the annual numbers of hotspots on peatlands in this district are much higher than would naturally be expected and justify making it a priority area for forest and peatland fires management. Forest and peatland fires increase greenhouse gas emissions into the air and contribute to global climate change (Masganti *et al.* 2014). Figure 3 shows that 2015 and 2019 had the densest hotspot distributions, while 2016-2018 had much lower hotspot numbers. Both the NINO 3.4 SST Index and Southern Oscillation Index indicate that 2015 had a strong El Niño event (Yananto & Dewi, 2016), whereas the El Niño in 2019 was weaker (BMKG, 2019). El- Niño events are associated with droughts in this region which had a clear impact on the density of hotspots in 2015 and 2019 as compared the other years which did not have El Niño conditions.
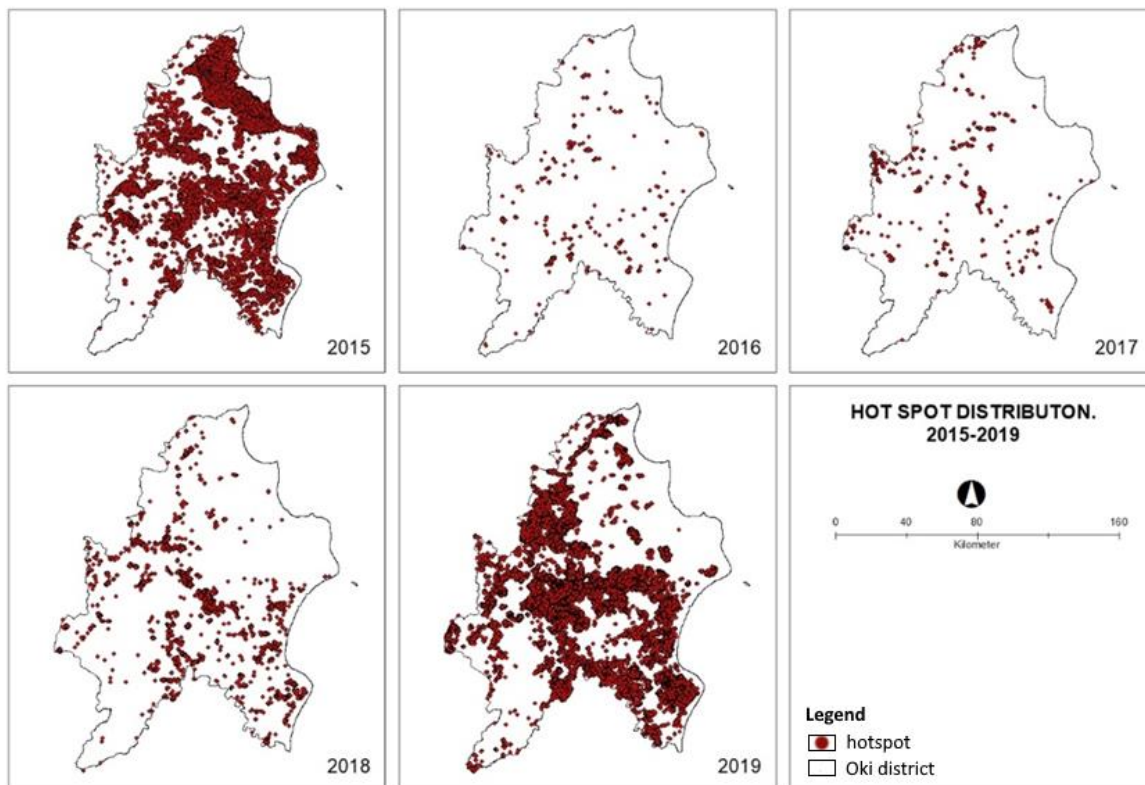

Figure 3. Annual Hotspot distribution at OKI District in the period of 2015-2019

Figure 4 shows that the numbers of hotspots from December until June, corresponding to the wet and early dry seasons, tend to be low but start rising in July as the dry season strengthens. The number of hotspots increases significantly and usually peaks in October; however, during El Niño

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conditions, large amounts of hotspots may be observed into November. In OKI District, September and October are the months most prone to fires and prevention activities are most critical at this time.
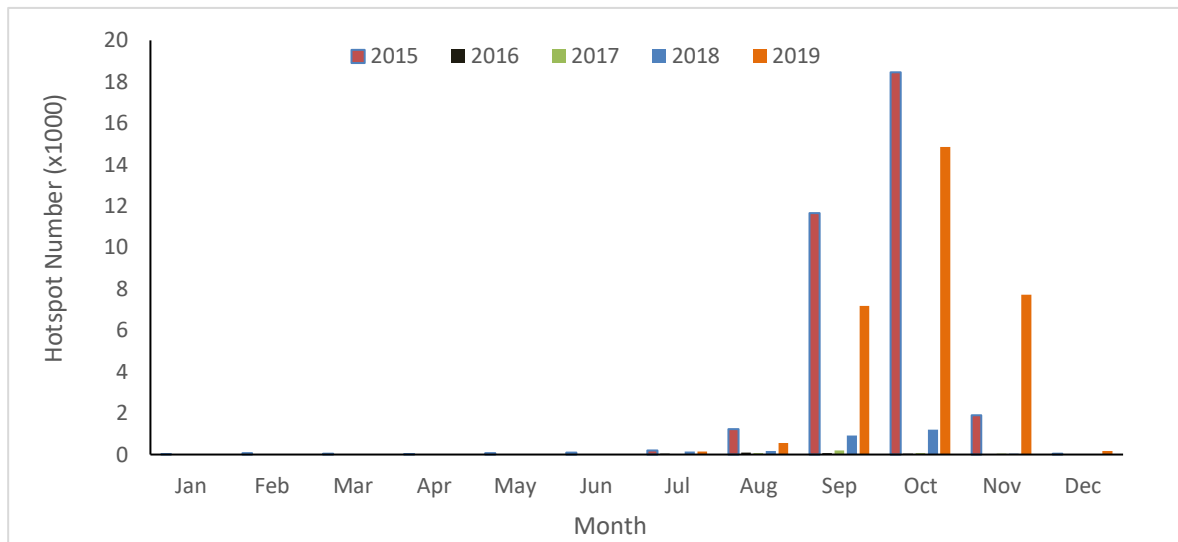

Figure 4. Monthly hotspot distribution at OKI District in the period of 2015 - 2019

Figure 5 shows the distribution of hotspots and monthly rainfall in OKI District. There was a strong relationship between rainfall and hotspot number from both MODIS Terra/Aqua and NOAA satellite data (Syaufina et al., 2014). In 2015, OKI District experienced a dry season starting from July (21mm rainfall) and reached peak intensity in September and October (0 mm) when no detectable rain fell. The number of hotspots in 2015 increased significantly as the dry season continued, rapidly growing to 11,647 in September and reaching 18,456 in October during this extremely dry period.

In 2016, by way of comparison, the highest number hotspots (90) were found in August, dropping to just a single hotspot in November. This dramatic reduction in hotspots was likely due to the extremely high annual rainfall (3,503 mm) that year. In 2017 hotspot numbers increased slightly from 2016, reaching a peak of 199 in September, the third consecutive month with rainfall amounts less than 100 mm. In 2016, only a single month dipped below 100 mm. The annual rainfall decreased slightly in 2018 (2,559 mm) compared to 2017 (2,647 mm). Indonesia began experiencing a weak El-Niño in October 2018 and only returned to normal conditions by the end of 2019 (BMKG 2019). The number of hotspots in 2018 began increasing in July and peaked at 1,206 hotspots in October. During the ongoing El Niño event in 2019, hotspot numbers increased to 7,165 in September and reached 14,844 by the peak in October. The dry season in 2019 (July – November) had the lowest monthly rainfall (0.5 mm) in August.
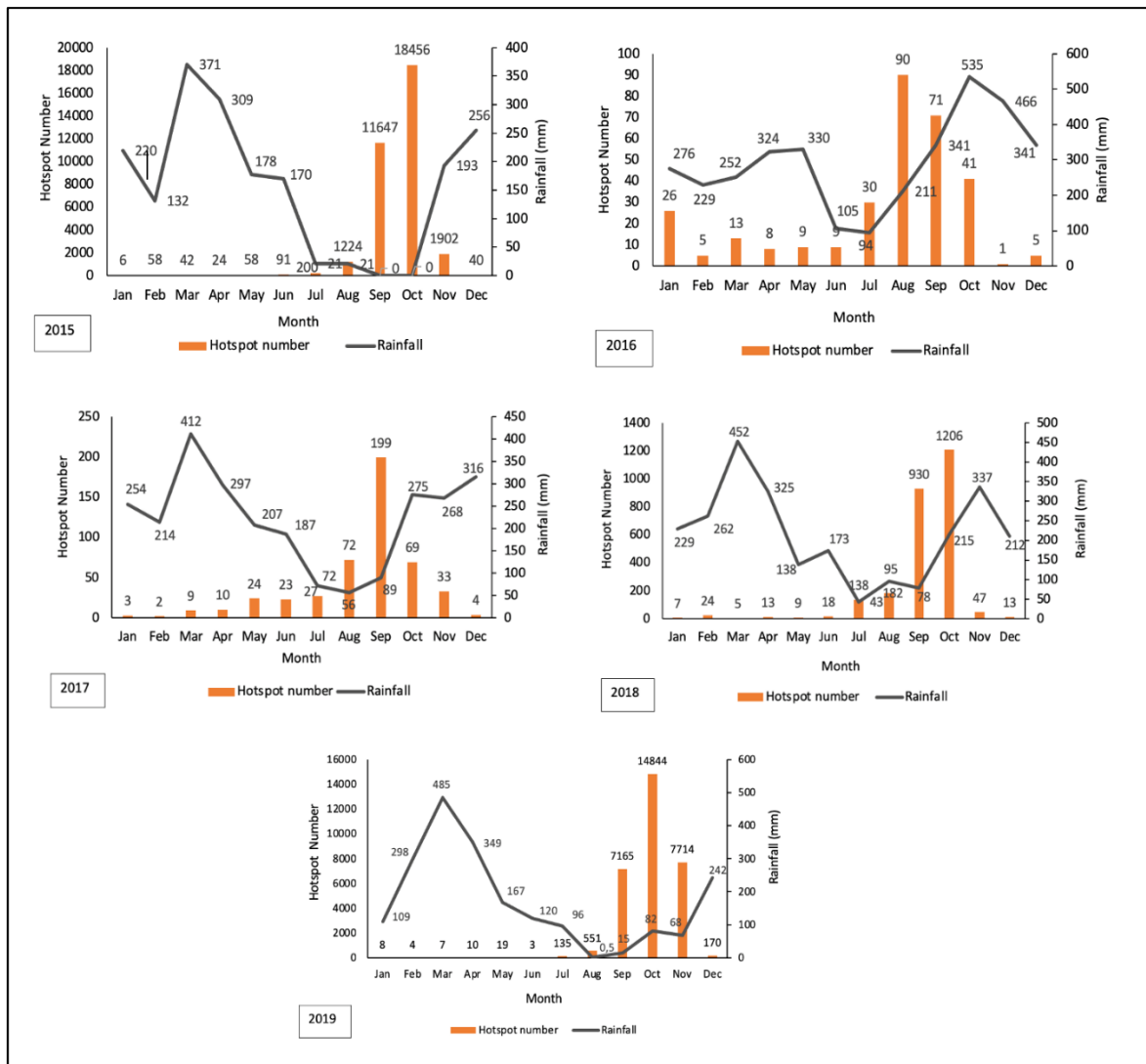
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Figure 5. Monthly hotspot and rainfall distribution at OKI District in the period of 2015 – 2019

3.2 The Relationship between Annual Hotspot Number and Rainfall

A linear regression analysis of hotspot numbers and annual rainfall was not significant (P value = 0.078); therefore, simple modeling with only annual rainfall is not sufficient for predicting the number of hotspots in any given year. The hotspot regression coefficient was negative (-22.236), indicating that the effect of the variable rainfall on the number of hotspots was inversely proportional. The negative relationship between hotspot number and annual rainfall can be seen more clearly in Figure 6, showing that hotspot numbers fell dramatically as annual rainfall increased from 2000-2500 mm. Although rainfall did not directly influence the number of hotspots as a fire indicator, it was an important factor influencing fuel moisture contents. As fuel moisture content drops this increases the flammability of the fuels.

Another factor strongly associated with the appearance of hotspots as forest and land fire indicators in OKI District is human land management activity. Although there has been a government prohibition on using fire in land preparation, it is still widely used because it is considered cheaper, easier, and faster than zero burning. Previous work has shown that the appearance of hotspots in the region is always related to forest and land clearing activities that are often conducted by burning. The cost of using fire in land clearing is only one-third to a quarter of zero burning techniques (Saharjo, 2006).
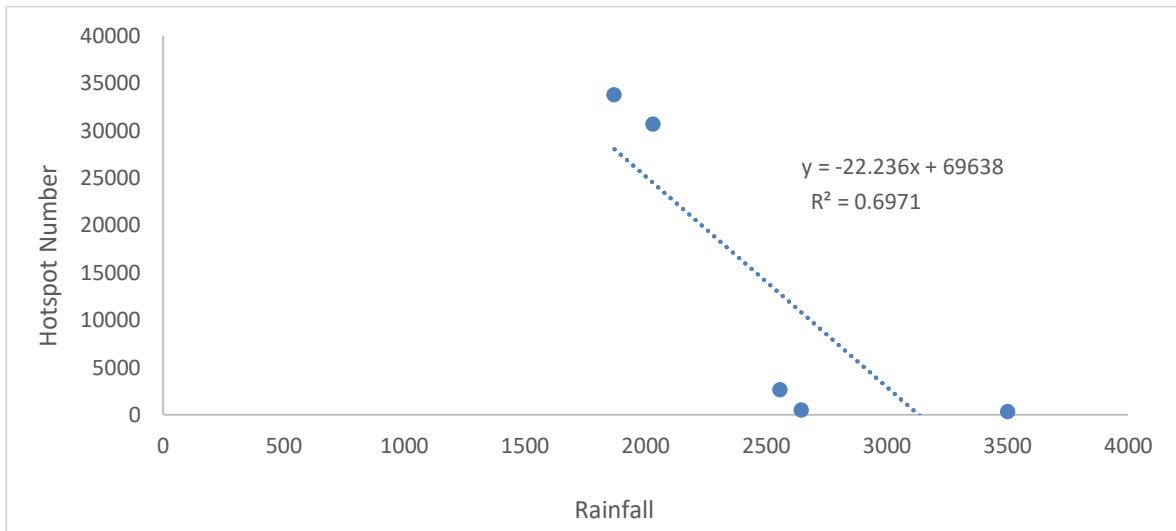
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Figure 6. Relationship between hotspot number and annual rainfall at OKI District in the period of 2015-2019

3.3 Burned Areas in the Period of 2015 - 2019

Based on the identification of burned areas in OKI District using Landsat 8 (Figure 7), the highest annual burned area occurred in 2015. The total burned area was 948,550 hectares, consisting of 410,132 hectares on peatland area and 538,418 hectares on mineral soils. The El Niño conditions in Indonesia in July 2015 triggered drought and worsened forest and land fires. Indonesia experienced severe forest and land fire in 2015, which burned peatland area of about 869,794 hectares (Trinimalingrum et al., 2015), and approximately 47.5% was located in OKI District.
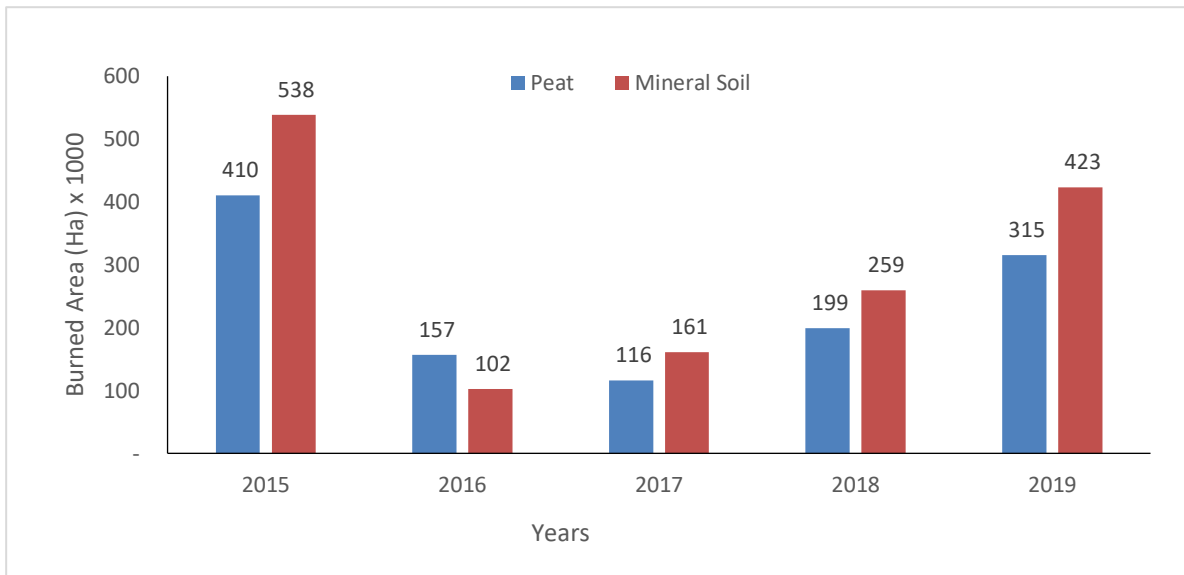

Figure 7. Temporal distributions of burned area at OKI District in the period of 2015-2019

In 2016, burned area decreased significantly (72.8 %) from the previous year. The burned area was approximately 258,521 hectares, with 156,775 hectares on peatland and 101,747 hectares on mineral soils. The decrease of forest and land fires was associated with strong La Nina conditions that increased rainfall during the dry season. In addition, due to the severe impacts of forest and land fires in 2015, the government had increased efforts to control forest and land fires in accordance with a decree by the Indonesian President that specified use of an early warning system, law enforcement, encouragement of community participation in preventing forest fires, air patrolling, improvements in forest and land governance, as well as coordination and synergy between the central and regional governments (MoEF 2017). In 2017, burned area in OKI District increased by 15 % (Figure 7). Total burned area was 276,617 ha, with 115,717 ha (37.8%) on

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peatlands. In 2018, burned area increased by another 65 % from the previous year, reaching 457,633 ha, 198,970 hectares of which occurred on peatlands. In 2019, the burned area in OKI District increased even further to 738,219 ha, with 314,851 ha on peatlands. Although weak, El-Niño conditions in 2018-2019 exacerbated the incidence of fires during this period.

Regardless of the number of hotspots, the spatial distribution of burned area each year (2015-2019; Figure 8) shows that substantial amounts of forest and land fires occur every year in OKI District. Even though there was no El- Niño phenomenon during 2016-2018, forest and land fires still continued to occur. Forest fire management, especially prevention, must become the top priority in OKI District to reduce the amount of perennial burning. Approximately 40 % of OKI District area is covered by peatlands. During the study period (2015-2019), the fires occurring on peatlands were numerous and quite large. In 2015, more than half of the peatland areas in OKI District burned (53.4 %) and in 2019, nearly half of the peatland area (41%) burned again. The peat fires are associated with human activities utilizing peatlands. Growing populations require continued conversion of peatlands to agricultural land in order to support the food security, fulfillment of raw materials for the paper industry, and requirements for plantation areas (Widyati, 2011).
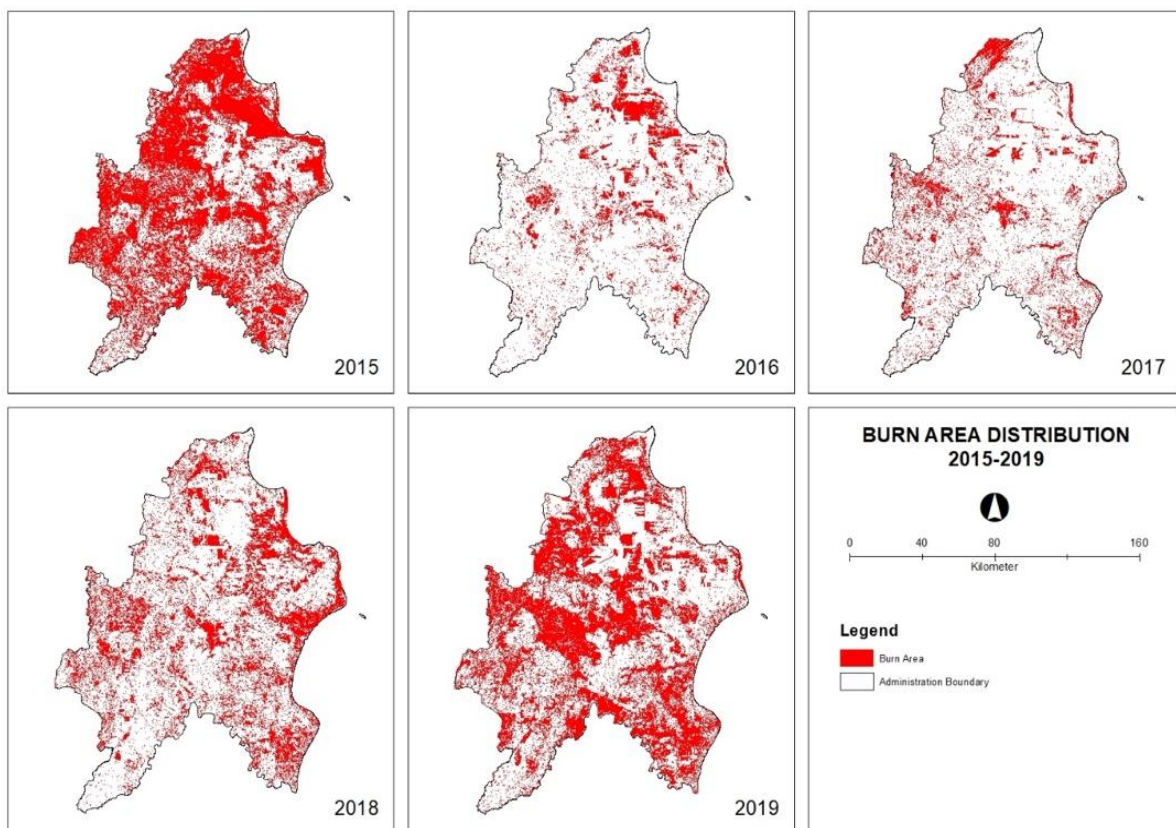

Figure 8. Spatial distribution of burned area at OKI District during 2015-2019

Nearly 100 % of forest and land fires in Indonesia are caused by human activities (Syaufina, 2008). The high intensity of human activities on peatland greatly increases the opportunities for forest and peatland fires. Improperly managed drainage canals cause the groundwater level to drop too far, leading the peat to become overly dry and prone to fires in the dry season. Based on Government Regulation Number: 57/2016 regarding the protection and management of peat ecosystems, having groundwater levels (GWL) more than 0.4 m below the peat surface is the standard criteria for considering peat damaged in cultivation areas. However, degraded forests and peatlands are more susceptible to fire and must be maintained in wetter conditions, with a critical GWL at 10 cm below the surface (Putra et al., 2018). Tulung Selapan sub-District in OKI District is dominated by peatlands degraded by logging or land conversion to oil palm plantations and it has been the largest contributor of haze from fires in South Sumatra Province (Solichin 2004).

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Previous studies have found that the majority of human actions that can cause forest and peatland fires in OKI District are related to the *sonor* system of land management (Nurhayati et al. 2020). *Sonor* is a system for preparing agricultural land by burning the peat surface to open the area and release important nutrients for rice to grow (Larastiti, 2018). Rice planting using *sonor* is usually conducted during a long dry season and is a longstanding practice that is still used by local populations in South Sumatra (Ratmini & Yohanes, 2014). Land preparation activities by communities and companies are the most common causes of fires in South Sumatra (Tarigan et al. 2015). Fire prevention activities in forest and peatland areas of Oki District need to focus on the human element.

4. Conclusions

The highest number of hotspots within the previous five years in OKI District was found in 2015, with roughly 72% located on peatlands, and the second highest was in 2019, 47 % of which was found on peatland. Examination of the number of hotspots throughout the years revealed the typical seasonality of hotspots in OKI District, with increasing numbers starting in July and reaching peak levels in September-October. This period corresponds with the lowest average monthly rainfall levels for 2015-2019, excluding the unusually wet La Nina year of 2016. Regression equations between annual hotspot numbers and annual rainfall were not significant (P value = 0.078); therefore, rainfall data alone cannot be used to predict hotspot numbers in the corresponding year. This is not a surprising result since forest and land fires are most closely associated with human land management activities in OKI District.

OKI District also experienced the two greatest areas burned by forest and land fires in 2015 and 2019, respectively. Severe drought conditions spawned by El Niño conditions exacerbated fires in both 2015 and 2019 causing burned area in peatlands as well as on mineral soils to be very high. More than half of the peatland area in OKI District burned in 2015 (53.4%) and close to half burned again in 2019 (41%). Though smaller in extent, fires still occurred in Oki District during the 2016-2018 period even though there was no El Niño, highlighting the importance of human activities in causing fires, especially on peatlands.

The Oki District is one of the most fire prone areas in South Sumatra and the dynamics of forest and peatland fires make prevention and control of forest and peatland fires a top priority if these lands are to be managed sustainably, with reduced regional health impacts from haze and lower greenhouse gas emissions.

Author Contributions: All authors contributed equally to this article

Conflict of Interest: The authors declare no conflict of interest

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