UTILISATION OF NASA - GFWED AND FIRMS SATELLITE DATA IN DETERMINING THE PROBABILITY OF HOTSPOTS USING THE FIRE WEATHER INDEX (FWI) IN OGAN KOMERING ILIR REGENCY, SOUTH SUMATRA

Hermanto Asima Nainggolan[1], Desak Putu Okta Veanti[2]*, and Dzikrullah Akbar[3]
[1]Mahasiswa Program Studi D4 Klimatologi, Sekolah Tinggi Meteorologi Klimatologi dan Geofisika
[2]Dosen Program Studi Klimatologi, Sekolah Tinggi Meteorologi Klimatologi dan Geofisika
[3]Dosen Program Studi Klimatologi, Sekolah Tinggi Meteorologi Klimatologi dan Geofisika
*e-mail: okta.veanti@stmkg.ac.id

Abstract. This study examines the link found between the Fire Weather Index (FWI) and the probability of hotspots in Ogan Komering Ilir District, Indonesia. Although meteorological observation in the area is limited, it is possible to utilise NASA - GFWED and FIRMS satellite data to analyse the ability of the FWI to explain hotspot events. The study aims to determine hotspot density based on the FWI for each season. Furthermore, it aims to establish the probability of hotspots based on FWI class and determination to identify the probability of forest fires in Ogan Komering Ilir. FWI data from NASA-GFWED and hotspot data from 2001 to 2016 from FIRMS were employed for the analysis. Conditional probability analysis was used to ascertain the likelihood of hotspots. The highest hotspot density occurs during the late dry season (SON), followed by the early dry season period (June, July, August). Hotspot density during the rainy season is very low. The probability of hotspots is highest during a high to extreme FWI (around 0.1 to 3.8%) and extreme Fine Fuel Moisture Code (0.1 – 6%).

Keywords: *FWI, Hotspots, Forest Fires, Conditional Probability*

1   INTRODUCTION

Forest and land fires are amongst the biggest disasters faced in Indonesia (Rasyid, 2014b). One of the most vulnerable provinces is South Sumatra. Based on data from the International Carbon Accounting System (INCAS), on average a 50,000 hectare area in the region was burned annually in the 12 years between 2001 and 2012. In addition, in 2015 there was a massive forest fire which lasted for weeks, contributing to the amount of greenhouse gasses emitted into the atmosphere, which is rising each year. During the forest fire of 2015, a huge quantity of greenhouse gasses was released, such as (in Gt) 806,406 CO_2, 8,002 CH_4, 96 N_2O, while pollutant emissions were (in Gg) 85,268 CO, 1,168 NOx, 340 SO_2, 3,093 NMVOC, 1,041 NH_3, 259 BC, 1,957 OC, 4,118 $PM_{2.5}$ and 5,468 PM_{10}. (Pribadi & Kurata, 2017)

To prevent forest fires, the government needs to strengthen local governments and the role of non-state actors (Alamsyah, Saptawan, Ermanovida, Yustian, 2019). Disaster management requires solid coordination between government agencies through communication, control and leadership (Budiningsih, 2017). *Badan Meteorologi Klimatologi dan Geofisika* (BMKG) provides information about fire weather to help other agencies to work more efficiently. Therefore, understanding of the relationship between meteorological conditions and fire is needed.

In South Sumatra Province, Ogan Komering Ilir is the region with the most

forest and land fire cases. More than 37,000 thousand hectares of forest and land in Sumatra Selatan was burned in 2018, 20,000 hectares of which was in the Ogan Komering Ilir Regency area. (BPBD in CNN Indonesia, 2018). Most of the land in Ogan Komering Ilir is peat; therefore, once a fire ignites, it is hard to control. Achyar et al. (2015) state that Ogan Komering Ilir is categorised as being very vulnerable to fire.

Forest and land fires in Ogan Komering Ilir affect South Sumatra, nearby provinces, and even neighbouring countries, such as Malaysia, Singapore, Brunei Darussalam and Thailand. Smoke produced by peat fires spreads to the surrounding area, disrupting daily activities and causing severe health problems. Moreover, it has been the cause of diplomatic tension between Indonesia and its neighbouring countries.

In general, there are several factors that influence vulnerability to forest and land fires. These include climate parameters (air temperature, rainfall, and humidity), population density, building density, availability of fire extinguishers, availability of water supply, and the presence of peat and wood vegetation. Changes in the value of these factors makes land very vulnerable and makes it very difficult to extinguish any fires (Latifah & Pamungkas, 2013).

Fires are indicated by hotspots downloaded from the NASA Fire Information for Resource Management System (FIRMS). Hotspots are the result of detection of forest and land fires at specific pixel sizes (eg, 1km x 1km), A hotspot can be detected when the satellite is directly above the hotspot in relatively cloud-free conditions using a certain algorithm (Kaufman et al., 2003). In general, hotspots are used as indicators of the potential for forest and land fires, meaning the more hotspots that are indicated, the greater the potential for

forest and land fires in particular areas (Autika et al., 2018).

Various studies to determine the chances of forest and land fires based on the fire index have been conducted.

The current fire weather index can be obtained through remote sensing satellites. One of the fire indices obtained using remote sensing technology is the Fire Weather Index (FWI), which is a system that has been developed since the 1960s in Canada. The FWI system consists of six structured fire code components, which describe the effect of weather, soil moisture conditions and the behaviour of a burning fire. The first three fire components are fuel moisture conditions. The next two components are qualitative indicators of the availability of fuel and the rate at which fire spreads when the fuel burns. The final index, FWI, indicates the intensity of the fire and how hard it is to control it once it ignites.

Some countries have used the FWI index to calculate fire potential, such as Argentina, New Zealand and Sweden (Van Wagner, 1974). Several studies have been conducted on the index, one of which compares the FFMC index and the FWI with the fire hazard behaviour system (SPBK) (Heriyanto et al., 2014). Other research (Veanti & Kloster, 2018) estimates the influence of weather parameter variability on changes in forest fires. This study mostly used FFDI. Therefore, the intention is to improve the research by using FWI, which is more complex and explains more diverse aspects by linking climate parameters and forest fires using fire indices.

FWI index data can be downloaded from the Global Fire Weather Database (GFWED) (Field et al., 2016). GFWED comprises eight different sets of FWI calculations, all using temperature, relative humidity, wind speed, and snow depth estimates from the NASA Modern-Era Retrospective Analysis for Research

and Applications, version 2 (MERRA-2) (Rienecker et al., 2011). Fire indicators are hotspots downloaded from NASA FIRMS satellite data.

Although forest and land fires are important, no study has analysed the conditional probability of hotspots based on the FWI in Indonesia. Therefore, this study aims to determine hotspot density based on the FWI and FFMC (Fine Fuel Moisture Code) in each season of December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), September-October-November (SON) and throughout the year. Furthermore, it aims to establish the probability of hotspots based on FWI and

FFMC classes and the suitability of FWI in determining the probability of forest fires in Ogan Komering Ilir.

2   METHOD
2.1   Location

The research location was Ogan Komering Ilir Regency, South Sumatra. Geographically, the district is located at 104° 20' to 106° 00' E and 2° 30' to 4° 15' S. Ogan Komering Ilir Regency covers an area of 19,023.47 Km^2, with a density of 39 people/km2. More than 570,000 hectares of the total area of Ogan Komering Ilir regency is peatland, of which 308,862 hectares is controlled by three private companies. Such peatland means the region is one of the most vulnerable and fire-prone locations, causing huge losses to the communities and companies that work or operate there.
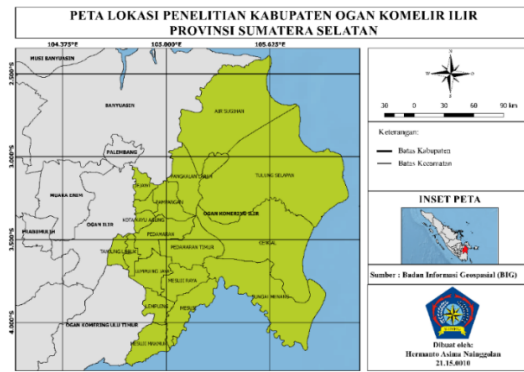

Figure 2-1: Map of Research Locations in Ogan Komering Ilir Regency

Data

The data used in the study can be seen in Table 2-1.

Table 2-1: List of Research Data

No.	Data Type	Data Period	Information
1.	Hotspot	December 1st, 2012 to December 31st, 2018	Data source: NASA-FIRMS. Resolution 1km x 1km
2.	FWI	December 1st, 2012 to December 31st, 2018	Data source: NASA-GFWED. Resolution 0.5⁰ x 0.625⁰
3.	FFMC	December 1st, 2012 to December 31st, 2018	Data source: NASA-GFWED. Resolution 0.5⁰ x 0.625⁰
4.	Observation data of four weather parameters: rainfall, air humidity, wind speed and air temperature	July 1 2015 to November 30, 2016	Data source: Palembang Kenten Climatology Station

In the study, the FWI and FFMC indices from GFWED were verified against those calculated from observational weather parameter data. Because no observations are made in the region, data from the closest climatological station, Palembang Kenten, are used. In addition, the hotspot data are not verified, so only hotspots with a high confidence level (80%) were selected for analysis.

FWI System

To calculate the FWI and FFMC, four weather parameters arere needed as input: air temperature, humidity, 10 meter wind speed observed at 12 pm, and total 24 hour rainfall (Van Wagner, 1974). In addition, the calculation also needs the moisture indices from the previous day.

The FWI system consists of three moisture codes: the Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC) and Drought Code (DC). Moisture codes are defined as the value used to calculate the moisture content of fuel in wet or dry conditions. In addition, moisture content is defined as the total mass of water contained in the fuel compared to the total mass of the fuel when it reaches dry conditions without any water in it (Stocks et al., 1989). The moisture code is inversely proportional to its moisture content. An increase in the value of the moisture code means less water content in the fuel. The decreasing rate of fuel moisture occurs exponentially (Van Wagner, 1974).

Table 2-2: Interpretations of the FFMC Class

FFMC Value	Class	Fire Characteristic
0-36	Low	Low possibility of ignition
37-69	Medium	Fire that propagates only on the surface
70-83	High	Fire quickly spreads, or moderate to high fire intensity
> 83	Extreme	Fast spread or high fire intensity, depending on BUI

FFMC is the moisture content from stems, twigs, leaves and other parts of plants that have fallen, and which are generally called fine fuels. The dry weight of these is $0.25 kg/m^2$, and the depth of the layer ranges from 0 to 5 cm from the ground surface. FFMC is an indicator of how easy a certain area ignites, especially in dry conditions. The FFMC value code is very sensitive to changes in daily temperature and relative humidity. (Van Wagner,1974).

FFMC is divided into four classes, as shown in Table 2-2, which explains the fire characteristics for each FFMC class and its danger rate.

The Duff Moisture Code (DMC) is the moisture content of medium-sized wood material or material that has been, or is being, decomposed in the soil. DMC is a layer of fermentation or topsoil on the forest floor. DMC dry weight is around $5 kg/m2$, and the depth of the layer ranges from 5 to 10 cm below the FFMC layer.

DMC time lag is modeled for around 15 days (Van Wagner, 1974).

The Drought Code (DC) is the moisture content of a solid piece of wood under the surface of the soil. DC has a dry weight of 44kg/m², and the depth of the layer ranges from 10 to 20cm under the DMC layer, with a time lag of 52 days (Turner, 1972).

Table 2-3: Interpretation of FWI Value

FWI Value	Class	Fire Characteristics
0-1	Low	Low intensity fire, which will spread slowly, and even extinguish itself.
2-6	Medium	Medium intensity fire. However, it can still be controlled directly using hand tools and water.
7-13	High	High intensity fire. Fire control requires an electric pump and/or the manufacture of firebreaks.
> 13	Extreme	Very high intensity fire, which are very difficult to control.

The next two indices measure fire behaviour and the total fuel available for burning. The first is the Initial Spread Index (ISI), which is a numerical index which estimates the rate of fire spread after ignition in very flammable areas. The ISI estimates the effects of wind and FFMC on the rate of fire spread and illustrates how fires will spread shortly after igniting, without consideration of the influence of available fuels. The second index is the BuildUp Index (BUI), which comprises the FWI components that take into account the total amount of fuel to be consumed based on a combination of DMC and DC components. The final component, the Fire Weather Index (FWI) is a numerical rating of fire intensity. It combines the Initial Spread Index and the

Buildup Index, and is suitable as a general index of fire danger (Van Wagner, 1974).

The FWI is divided into four classes (low, medium, high, extreme), as shown in Table 2-3, and explains fire intensity.

Conditional Probability

Observation data using the Pearson correlation method was used to determine the feasibility of the data in representing inadequate observation data. If the correlation between FWI and FFMC obtained from remote sensing results and that obtained from observational weather data has a significant value, then the FWI and FFMC data are considered suitable for use in research.

Ogan Komering Ilir Regency was divided into several grids, with each grid 0.625 x 0.5 degrees in size. The division was based on the resolution of the FWI and FFMC data from the remote sensing system, so that spatial analysis could be performed more efficiently. The research area can be seen more clearly in Fig. 2-2.
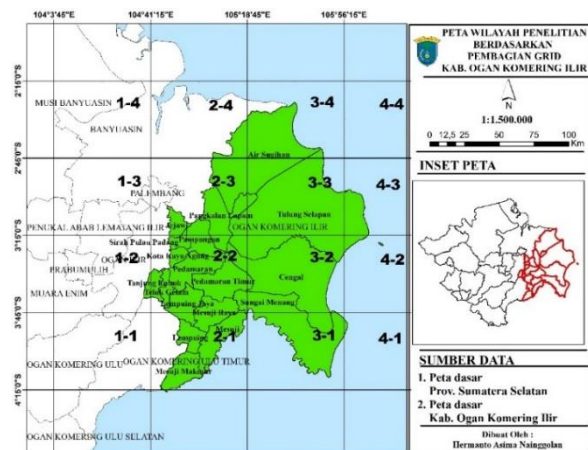

Figure 2-2: Map of the study area divided into grids sized 0.625 x 0.5 degrees

The grids included in the research area are ones which cover the land area of the Ogan Komering Ilir district. Eleven grids were produced, which are the focus of the research area and are designated 1-2, 2-1, 2-2, 2-3, 2-4, 3-1, 3-2, 3-3, 3-4, 4-2 and 4-3.

The downloaded hotspot data were regridded at a resolution of 0.5 x 0.625 per grid to match the resolution of the FWI data. The number of hotspots per grid is considered to be 1 if there is a fire event and 0 if there is no fire event. Note that if more than one event occurs on the same day, the hotspot value is still considered to be 1.

Probability is a value that is used to measure the level of occurrence of a random event, with the scale measured in a range of 0 to 1. The probability of 0 means an event is unlikely to occur, and the probability of 1 means an event must occur (De Groot et al., 2012).

If event A are hotspots, then the climatological probability of the event is P(A). Then, if FFMC and FWI are considered as event B, with the probability P(B), conditional probability can be determined. Conditional probability is the possibility that event B will occur, provided that event A has occurred first. Conditional probabilities are used in this study to determine which indexes in the range of values will produce a specific number of hotspots in an area of the grid. Conditional probability includes a condition that can limit the sample space for an event. The conditional probability notation is expressed by:

$$P(B|A) = \frac{P(A \cap B)}{P(A)} \quad (3\text{-}1)$$

The probability of a "B" event is required by an "A" event. Conditional probabilities occur naturally in a study in which the results of a trial can affect those of subsequent trials. If the probability of an event changes when we consider the first event, then it can be said that the probability of event B occurring depends on the occurrence of event A (Pourghasemi et al., 2012).

Conditional probability is used as a method of determining the probability of a hotspot based on the FWI interpretation value. Symbol "A" represents the probability of a hot spot, while symbol "B" represents the value of the FWI interpretation. Therefore, conditional probability states the probability of a hotspot occurring with certain FWI values.

3 RESULTS AND DISCUSSION
Data Comparison

FWI data and FFMC observations were calculated based on weather parameters such as rainfall, air temperature, humidity and wind speed. The four types of data were then processed based on the FWI and FFMC calculation formulas from Van Wagner (1974) to obtain the required index values. The FWI and FFMC observation data were then correlated using Pearson correlation with the FWI and FFMC data from GFWED. The correlations of the two types of data are shown in the distribution plot graph in Fig. 3-1.
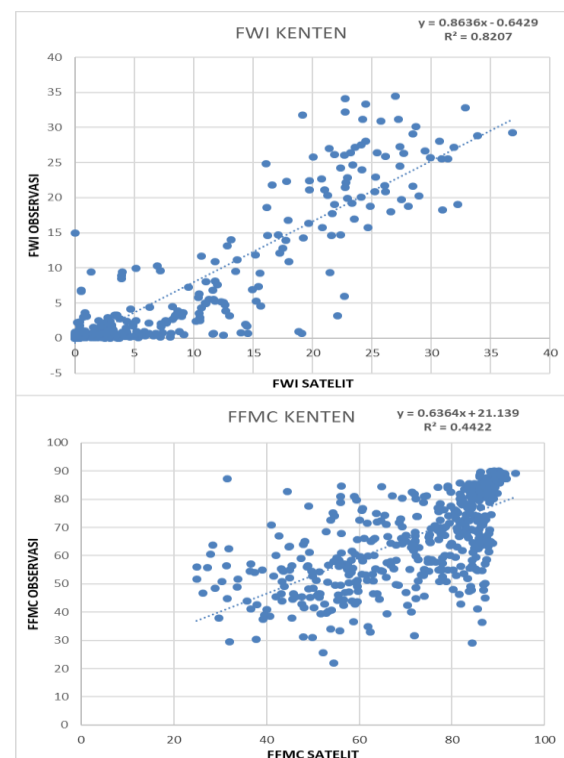

Figure 3-1: Correlation graph of FWI and FFMC satellite data and observation data

Daily observational data for 519 days from 1 July 2015 to 30 November

2016 were used. The correlation between the observational FWI and FFMC and the data from GFWED was positive. Therefore, the fire indices derived from observation and those from GFWED had a statistical relationship. The value of R^2 on FWI was 0.8207, while that on FFMC was 0.4422. These correlation values were considered large enough for the FWI and FFMC reanalysis data to represent the FWI fire index for the research in the Ogan Komering Ilir district.

Seasonal Distribution of Hotspots

Figure 3-2 shows that the distribution of hotspots in Ogan Komering Ilir in each season. During the second half of the dry season in Indonesia (September, October and November), the concentration of hotspots is at its highest. This is similar to the results from Meiriza et al. (2017), who found that the "Based on temporal aspects most hotspots occurred on August, September, and October in South Sumatera with hotspots data from 2005 to 2015.
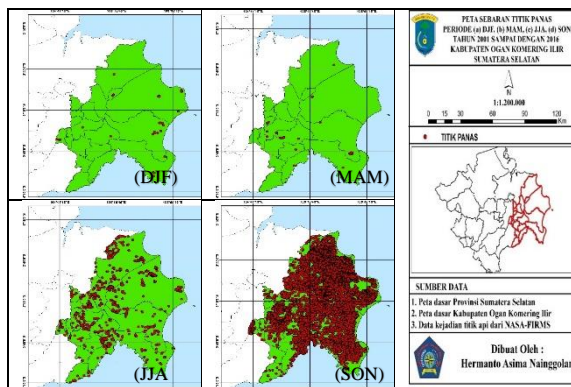

Figure 3-2: Distribution of hotspots in each seasonal period

The concentration of hotspots varied between the different areas. The number occurring indicates how vulnerable a point is, and how often it has experienced a forest fire. The densest hotspots are in grid 1-2, and the sparsest in grid 4-2. This situation is possibly because only a small portion of the Ogan Komering Ilir district is represented on the grid. With regard to grid 4-2 having the fewest hotspots, this due to the fact that almost all of the grid is located in the ocean, with the land area bing only a small part.

Conditional Probability Analysis

The probability of hotspots occurring during certain FWI and FFMC events is shown in Table 6, which indicates the probability for each FWI and FFMC class. Low FWI/FFMC indicates that the weather conditions are not suitable for fires, while the extreme class shows the opposite. This study found a close relationship between the probability of hotspots and FWI/FFMC indices. The highest hotspot probability is found in high or extreme FWI classes. Consequently, extreme classes of FFMC always show the highest hotspot probability (Table 3-1). The non-existence of hotspots during low FFMC is because ignition is impossible. However, although there is a possibility that fires might take place during low to medium FWI or during medium to high FFMC, Ogan Komering Ilir is more vulnerable during high to extreme FWI and/or extreme FFMC. Therefore, the influence of atmospheric conditions on forest fires is clear.

Table 3-1: Hotspot probability for each class of FWI and FFMC on the 11 Ogan Komering Ilir district grids

	FWI					FFMC				
GRID	Low	Medium	High	Extreme	TOTAL	Low	Medium	High	Extreme	TOTAL
1-2	2.7	2.6	3.2	1.8	10.4	0.0	1.9	2.5	6.0	10.4
2-1	0.4	0.5	1.0	2.8	4.7	0.0	0.3	0.6	3.8	4.7
2-2	0.7	1.3	2.3	3.3	7.6	0.0	0.5	1.2	5.9	7.6
2-3	0.5	1.1	2.4	1.9	6.0	0.0	0.3	0.9	4.7	6.0
2-4	0.5	1.1	2.4	1.9	6.0	0.0	0.3	0.9	4.7	6.0
3-1	0.4	0.9	1.2	3.8	6.2	0.0	0.3	1.0	4.9	6.2
3-2	1.0	1.2	1.7	3.0	7.0	0.0	0.8	1.4	4.8	7.0
3-3	0.6	1.0	2.3	3.0	6.9	0.0	0.5	1.1	5.2	6.9
3-4	0.3	0.5	1.3	2.4	4.5	0.0	0.3	0.6	3.6	4.5
4-2	0.1	0.1	0.1	0.1	0.3	0.0	0.1	0.1	0.1	0.3
4-3	0.2	0.2	0.4	1.3	2.1	0.0	0.2	0.2	1.7	2.1

Even so, studies which compare the influence of climatological conditions and human activities on forest fires are still needed. Ones which have confirmed the influence of human activities on forest fires (Tuhulele, 2014; Mapilata, et al. 2013) and those which have verifed the impact of atmospheric conditions (Aflahah, 2019; Syaufina, 2018) have already given us strong evidence of the relationship between forest fires, human activities and natural causes. However, the interplay between all the factors is less understood and needs further research.
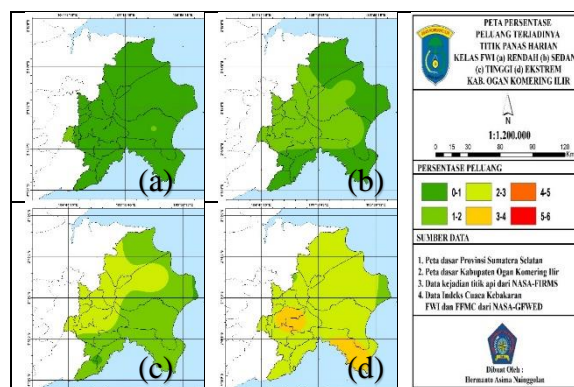

Figure 3-3: Probability of daily hotspots based on the FWI index for each class:
(a) low, (b) medium, (c) high, (d) extreme

The four images shown in Figure 3-3 are the results of interpolation from the probability of the occurrence of hot spots for each class on the eleven grids in Ogan Ilir Regency. From the four maps, the low

and medium classes show a smaller chance of hot spots compared to the high and extreme classes. The highest probability is in the range of 3 to 4 percent for the extreme FWI class (orange), while for the high class, the highest odds are in the range of 2 to 3 percent. For the middle class, most have a 1 to 2 percent chance, and in the low class most only have a 0 to 1 percent chance in almost all regions of Ogan Komering Ilir Regency.
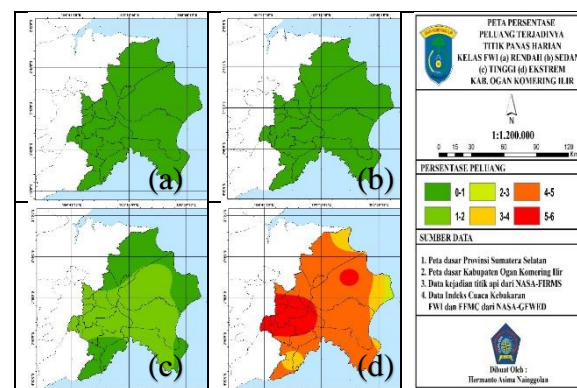

Figure 3-4: Probability of daily hotspots based on the FFMC index for each class:
(a) low, (b) medium, (c) high, (d) extreme

In particular, the low FFMC class on the whole grid has a 0% probability. Statistically, there is absolutely no chance of a hotspot occurring in the low class over the whole grid. Meanwhile, the range is 0 to 1 percent for medium FFMC. For high FFMC, the chance of hotspots in all regions is higher than in the previous class (in the range of 2 to 3 percent). On

the other hand, the extreme FFMC class shows significant differences when compared to the previous class. In the extreme FFMC class all regions show a chance of hotspots of above 3 percent, with the highest percentage of opportunities being in the range of 5 to 6 percent in some regions (shown in red).

The rate of hotspot occurence varies between seasons. The density of hotspots for each season can be seen in Figures 3-5 to 3-14.
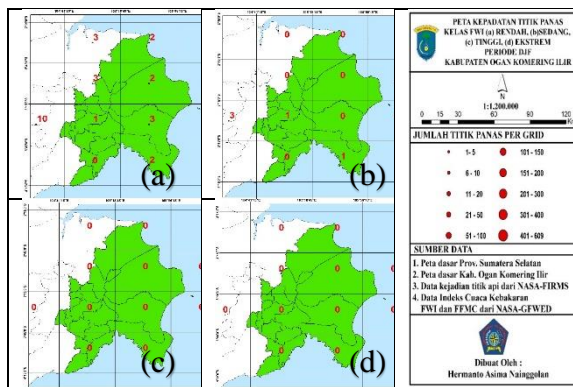

Figure 3-5: Hotspot density December, January, February (DJF) period. FWI class: (a) low (b) medium (c) high (D) extreme

In the DJF period (December January February) the density of hotspots in each grid is very low. This is in line with the results of Prayoga et al. (2017). However, it can be seen that in this season, hotspots actually occur in low and moderate FWI classes. This is interesting, because the high and extreme FWI classes actually did not experience any hotspot events at all, while the low and moderate classes did experience

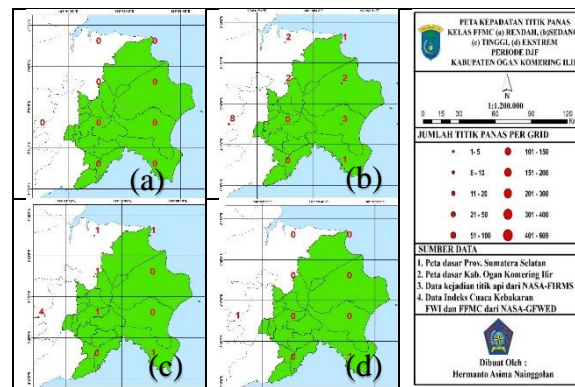hotspot events, with even the low class densely packed with hotspots.

Figure 3-6: Hotspot density December, January, February (DJF) period. FFMC class: (a) low (b) medium (c) high (D) extreme

IN the DJF FFMC index period (December, January and February), the most numerous hotspots were in the medium class, followed by the high class. In the low class there are no hotspots at all, and in the extreme class just one occurence. Compared to the FWI index, in the DJF period there was little resemblance to the points where the hotspots appeared most densely in the class that should have had the lowest chance of fires.

The general conditions in the DJF period need to be noted. This distribution is normal because this season rarely has high to extreme FWI and FFMC indices due to high rainfall and humidity. Besides, there are only a miniscule number of hotspots, which might not be related to large forest fire events, but to other activities.
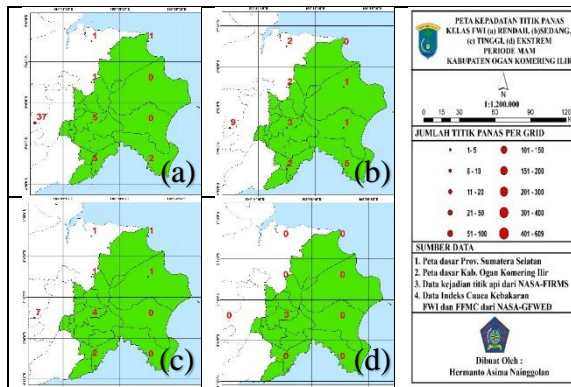
Figure 3-7: Hotspot density March, April, May (MAM) period. FWI class: (a) low (b) medium (c) high (D) extreme

Hotspot density in the MAM period is still small (less than 10), and these are spread evenly across all FWI classes. Hotspots start appearing in several grids in the high and extreme classes.
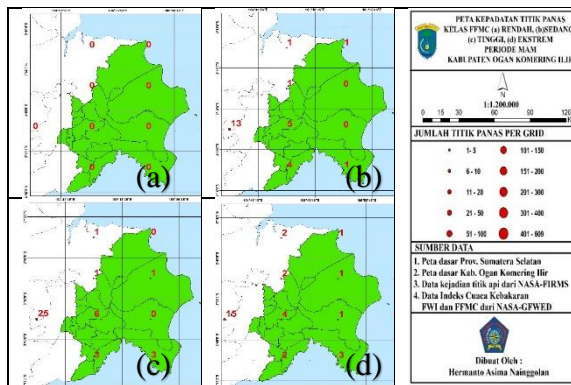

Figure 3-8: Hotspot density March, April, May (MAM) period. FWI class: (a) low (b) medium (c) high (D) extreme

The FFMC maps for the MAM period show higher hotspot densities compared to the DJF period. The number is similar in the medium, high and extreme FFMC. Although MAM is a transitional period from the rainy to the dry season, there is no notable increase in the number of hotspots. This indicates that the fuel is not dry enough and the weather does not support the emergence of forest fire.
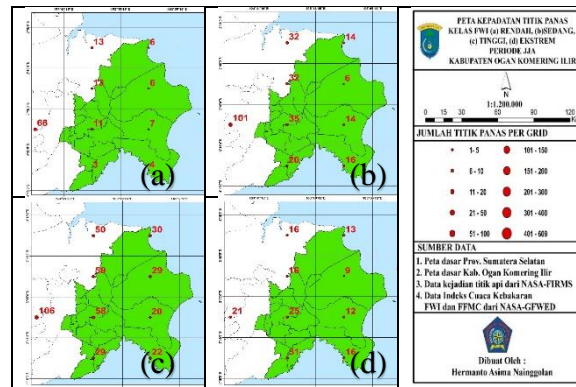

Figure 3-9: Hotspot density June, July, August (JJA) period. FWI class: (a) low (b) medium (c) high (d) xtreme

During the JJA period, the densest hotspots occur on the high FWI map, followed by hotspots on the extreme FWI map. It can be seen that the low and moderate classes also contain hotspots, but their density is lower. Hotspot density in general is higher compared to the previous seasons. During the JJA period, rainfall is low and temperatures are high. Therefore, more hotspots are expected.
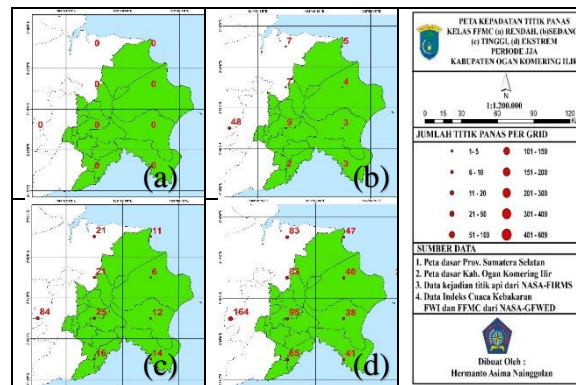

Figure 3-10: Hotspot density June, July, August (JJA) period. FFMC class: (a) low (b) medium (c) high (d) extreme

In the JJA FFMC index, the densest hotspots occur in the extreme class, followed by the high class. Meanwhile, in the middle class, there are still several hotspots. In the low class, no hotspots

occur. The JJA season is characterised by low rainfall, low humidity and high temperatures, resulting in the increase from high to extreme FWI and FFMC. Low rainfall during August was recorded in the study by Meliani et al. (2020). Compared to rainfall in April, in August it is considerably lower. In this period, the FFMC index is increasingly relevant to explain the emergence of hotspots in Ogan Komering Ilir district.
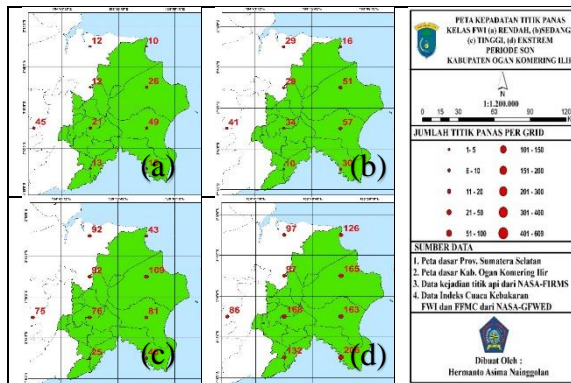

Figure 3-11: Hotspot density September, October, November (SON) period. FWI class: (a) low (b) medium (c) high (d) extreme

In the SON period, the FWI experiences the most intense hotspots in the extreme class, followed by the high class, while for medium and low classes, there are still several hotspots. In this season, over the entire grid the most dominant hotspots occur in the extreme classes. In line with the dry conditions of the season, the FWI index is increasingly relevant to the incidence of hotspots.

In line with the hotspot conditions in the previous FWI index, in the FFMC index the most intense fires occur during the SON season period (September, October and November), with the most dominant in the extreme classes. Hotspots occur relatively frequently in the high class, and several times in the medium class. On the other hand, in the

lower classes, there are no fires. The SON season period, which is the dry season shows that the FFMC index is more suitable for the hotspot events in Ogan Komering Ilir district.
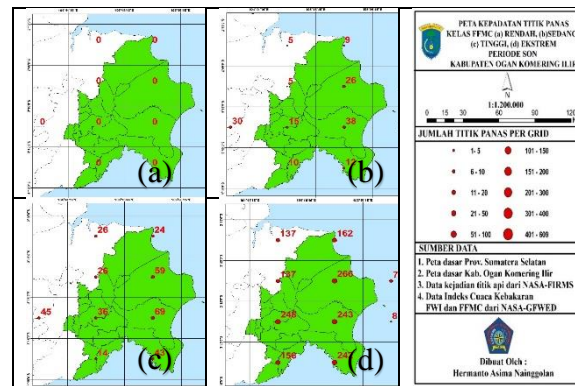

Figure 3-12: Hotspot density September, October, November (SON) period. FFMC class: (a) low (b) medium (c) high (d) extreme
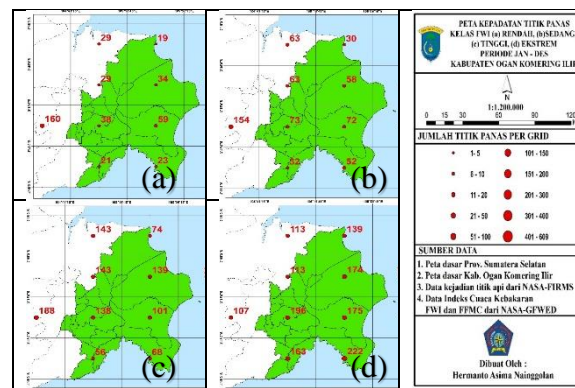

Figure 3-13: Comparison of FWI interpretation classes January-December seasons. (a) low (b) medium (c) high (d) extreme

The FWI index throughout the year, from January to December, has the most intense hotspots in the extreme class, followed by the high class. Hotspots occur several times in the low and moderate classes, but do not dominate. For this reason, the FWI index is generally suitable with regard to the occurrence of hotspots. When it shows values that are in the range of the high or extreme classes, the potential for hotspots is very high.
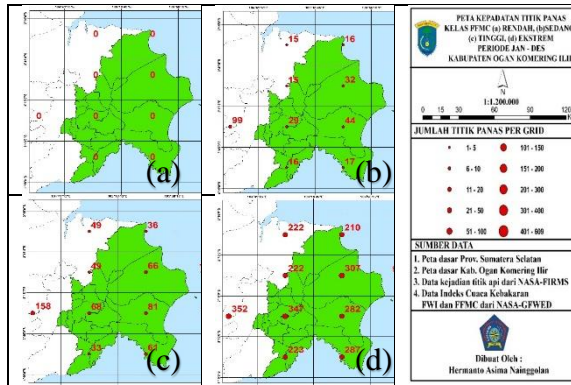
Figure 3-14: Comparison of FFMC
interpretation classes January-
December:
(a) low (b) medium (c) high (d) extreme

On the FFMC index throughout the year, the densest hotspot events occur in the extreme classes, followed by the high classes. Several hotspots occurred in the medium class, but in the low class there were no hotspots. This indicates that the FFMC is relevant to the occurrence of hotspots; when it shows values that are in the high or low class, hotspots have the potential to be relatively large.

4   CONCLUSION

The highest hotspot density takes place during the late dry season (SON), followed by the early dry season (JJA). Hotspot density during the rainy season is very low. The probability of hotspots is highest during high to extreme FWI (around 0.1 to 3.8%) and extreme FFMC (0.1 – 6%). FWI and FFMC can link weather conditions and the occurrence of hotspots well.

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AUTHOR CONTRIBUTION

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