Thermal Hotspots Distribution of MODIS Aqua/Terra
Satellite in Humbang Hasudutan Regency, Northern Sumatra

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Abstract. The hotspot of MODIS Aqua/Terra represents the high risk of land/forest fire due to an extreme temperature over the hotspot location. Spatial-temporal analysis of the hotspot can be used to map the regions with a high vulnerability of forest/land fires. This study has an objective to use hotspot data from MODIS Aqua/Terra to map the forest/land fires over the Humbang Hasudutan Regency from 2001 to 2019. In spatial, the hotspot mostly occurs in the eastern part of the study area (Doloksanggul and Pollung), which this area has assigned as the peatland area. Based on land cover, the hotspot often detected over the dryland agriculture, dryland with shrubs, and bare soil. In temporal, the hotspot mostly increases during the dry seasons such as February, June, and July. The hotspot decreases during the wet season, such as January, October, November, and December. Besides, there was an inversely proportional between the number of detected hotspots and rainfall over the study area.

1. Introduction
Indonesia is one of the tropical countries and is included as the third-largest peatland in the world. The peatland area is around 265,500 km², spread on the islands of Sumatra, Kalimantan, and Papua. Based on the breadth, the Indonesian peatland area is half of the tropics’ peat area [1]. According to the 2008 reports, Indonesia's peatland stores are the third-largest carbon stock in the world (after Canada and Russia), which is around 54,016 Mton. One of the areas in North Sumatra that have peatlands is the Humbang Hasundutan Regency (starting now referred to as Humbahas), which has an estimated peatland of 2,358 ha [2]. Dolok Sanggul Sub-district, Pollung Sub-district, and Lintong Ni Huta Sub-districts are sub-districts with a peat area in Humbang Hasudutan Regency. The type of peatland in the Humbang Hasudutan Regency is a tophogenic peat type or highland peat type with many benefits such as carbon stock storage and a Lake Toba catchment area. Peat utilization activities that have occurred in Humbang Hasudutan Regency have become a problem given the number of emissions that will be generated from these activities and affect their carbon storage capacity [2]. Peatland is a land rich in organic matter formed from the remains of plants that have not been weathered entirely.
due to environmental conditions saturated with water and nutrient-poor. Peatlands whose primary function as carbon storage can change into carbon source areas and other greenhouse gases, the greenhouse gases emitted by peatlands are CO2, CH4, and N2O; among these three gases, CO2 is the most critical greenhouse gas due to its relatively large amount.

Hotspots are hotspots that are indicated as locations of forest and land fires. This parameter has been used extensively in various countries to monitor forest and land fires from satellites. The way to detect forest and land fires is by observing hotspots. Hotspots (hotspots) can be detected with NOAA (National Oceanic and Atmospheric Administration) satellites equipped with AVHRR (Advanced Very High-Resolution Radiometer) sensors. In detecting forest fires, NOAA satellites do not directly detect fires (temperature), but those detected are hotspots. Hotspots can be detected with NOAA satellites equipped with AVHRR sensors that work based on the thermal energy emitted from objects observed from an area with a temperature of 42°C.

This satellite is often used to detect the region because one of its sensors can distinguish surface temperatures on land or sea. Another advantage is that the satellites often visit the same place twice a day and night; another advantage is the low price. A hotspot (hotspot) can reflect an area that may be partially or completely burned because it does not indicate precisely how large the area burned. The number of hotspots can vary significantly from a subsequent measurement depending on the measurement time of the day (fire activity decreases at night and highest in the afternoon), weather (the sensor used cannot penetrate clouds and smoke) and what organization which provides such data (there is no temperature or temperature threshold standard to identify hot spots) [3].

Hotspots provide little information if they are not supported by further analysis and interpretation. A group of hotspots which detected in a large place continuously is a good indicator of fires (hotspots). Hotspot data is useful when combined with information such as land use, crop cover, animal habitat, or other maps. The bias or geographic error of a hotspot can be as far as 3 km [3]. This hotspot data is free downloadable by the public, but the use of this data for study the distribution of hotspots is rarely used by the public. This study's objective is to use MODIS Aqua / Terra satellite to assess the risk of forest and land fires in the Humbang Hasudutan Regency (Humbahas) based on the distribution of hotspot from MODIS satellite data. The result of this study can be used as a reference for Humbang Hasudutan District to anticipate forest fires over the study area.

2. Material and Methods

2.1. Study area

The study area is located in the central part of North Sumatra Province. Humbang Hasudutan Regency is located on the lines 20°1’ – 20°28’ LU and 98°10’ – 98°58’ BT. The area of Humbang Hasudutan Regency is 251,765.93 Ha and consists of 10 sub-districts (Pakkat sub-district, Onanganjang sub-district, Sijamapolang sub-district, Lintongnihuta sub-district, Paranginan sub-district, Doloksanggul sub-district, Pollung sub-district, Parlilitan sub-district, Tarabintang sub-district, and Baktiraja sub-district).

2.2. Data used

We used several data, including land use and land cover data, precipitation, Humbahas Regency administration map data. Hotspot data can be downloaded from MODIS aqua/terra. MODIS (Moderate Resolution Imaging Spectroradiometer) is the main sensor on the Terra satellite and Aqua satellites that orbit the earth polarly (north to south) at an altitude of 705 Kilometers and crosses the equator at 10:30 and at 22:30 local time [4]. The width of land coverage on the surface of the earth each rotation is around 2330 Kilometers. Reflections of electromagnetic waves received by MODIS (Moderate Resolution Imaging Spectroradiometer) sensors are 36 channels (36 wavelength intervals), ranging from 0.620 μm to 14.385 μm (1 μm = 1 / 1,000,000 meters). MODIS (Moderate Resolution Imaging Spectroradiometer) data using the brightness temperature data for channel 21 or channel 22 (T4) and channel 31 (T11). Canal 32 for cloud masking, the brightness temperature for this channel is denoted by (T12) [4] can be used to detect the location and distribution of hotspots. The hotspot data
The precipitation data relied on satellite processing, the Climate Vulnerabilities Group InfraRed Precipitation with Station data (CHIRPS) from January 2001 to December 2019 with a spatial resolution of 5 km. CHIRPS is a new 30+ year quasi-global groundwater level dataset. It has area scanning from 50°S to 50°N in all longitudes, which is the daily data that has duration from 1981 to present. For spatial resolution, CHIRPS incorporates 0.05° resolution satellite imagery, which validates by station data to create gridded groundwater level time series for many applications. Since February 12th, 2015, version 2.0 of CHIRPS is finished and opened to the public. Compared to other satellite data (GSMaP, IMERG, and CHIRPS,) CHIRPS has a better correlation to the observation data in Indonesia, especially for monthly periods [5]. We also used the Humbahas Regency administration map data from BPN (2010) and Land cover from the Indonesian Forestry Planning (2011).

2.3. Methods
The steps taken in this study are as follows: the MODIS satellite data processing process includes downloading, extracting, and displaying data in spatial form. The format of the data obtained from the website is in the form of shapefile so that it can be directly plotted using ArcGIS software. Second, the TRMM satellite data processing process includes downloading, extracting, and displaying data in spatial form. Data processing is performed using GrADS. Third, Overlay between the MODIS satellite and Humbahas versus administration map and MODIS Satellite versus Land Cover. Spatial analysis is carried out to determine the pattern of hotspots distribution both by village / sub-district and land cover. Fourth, Comparison of MODIS satellite data vs. TRMM satellite has been done to find out the relationship between hotspots and average rainfall in Humbahas regency.

3. Results
3.1. Hotspot spatial distribution
The map was based on hotspot data from the MODIS Aqua / Terra satellite from January 1, 2001 to 31 December 2019. Based on available MODIS data, 575 were received in the Humbahas Regency (Figure 1).

![Figure 1. Hotspots distribution in Humbang Hasudutan Regency from 1 Jan 2001 to 31 December 2019](image)

Basically, the data are being classified into three classes based on the confidence level of MODIS Aqua/Terra. The total of hotspots is about 744 hotspots from 2001 to 2019. As many as 33 points were included as the “Low” of confidence level. For the moderate confidence level, we found 602 hotspots in the “Medium” category. There were 109 hotspots which assigned as “high” of the confidence level.
In general, the distribution of in Humbahas is spreading only in the western part, eastern part, and southern part. In this study, a hotspot distribution overlay was carried out on the administrative map of the Humbahas Regency, where the Humbahas Regency consisted of 10 districts and 91 villages. The overlay distribution of and Humbahas Regency administration map show that the distribution mostly occurs in Pollung Sub-district, Doloksanggul Sub-district, and followed by other sub-districts (Figure 2).

![Figure 2. Distribution of the hotspot based on the district in the study area](image)

3.2. Spatial pattern based on land cover
In addition to overlaying the administrative map of the Humbahas Regency, this study also analysed the relationship between distribution and land cover. It will be useful and vital to investigate the relationship between land cover and in Humbahas Regency. Broadly speaking, as many as 40% of the 744 detected were on land cover in the form of dryland agriculture (Pt / 20091). Based on the classification, all agricultural activities on this dry land include dry fields, mixed gardens, and fields. All agricultural activities on dry land such as dry fields, mixed gardens, and fields. Based on SNI 7645-2010 concerning Land Cover Classification by Bakosurtanal, Dryland Agriculture is included in the classification of agricultural land carried out on dry land. Dryland is characterized by low rainfall (< 250 - 300 mm / year). Drought index (ratio/ratio between rainfall and evapotranspiration is less than 0.2), plant variation is minimal (only shrubs, grasses, and small trees in certain areas), very high temperatures (+ 49 degrees Celsius in summer), the texture of the soil is sand and has high salination of the soil and groundwater caused by high evaporation and infiltration.

Typically, the types of plants on dry land are corn, sweet potatoes, and beans. In addition to Dryland Agriculture, we detected in dryland agriculture with Shrubs (Pe / 20092), as many as 18% of the 744 were detected. This type of land cover includes all types of dryland agriculture intermittent with shrubs, shrubs, and logged forests. This type of land cover often appears in areas of shifting cultivation and rotation of planting karst land. The third type of land cover where are detected is open land (T / 2014) as much as 17% of the 744 detected. Open land is the entire appearance of open land without vegetation (outcrops of mountain peaks, volcanic craters, sandbanks, beach sand), open land after the fire, and open land covered with grass/grass. The appearance of open land for mining is
explained by mining, while open land used for land clearing is classified as agriculture, plantation, or plantation forest.

Figure 3. Hotspot based on land cover in Humbahas Regency

3.3. Hotspots distribution based on time series

In addition to conducting spatial analysis, a temporal analysis is based on annual and monthly time series to determine the general pattern of during the last 19 years in Humbahas Regency. By using linear regression, it was found that there were variations in the form of fluctuations in the number of detected each year in the 19 years of existing data. However, based on linear regression analysis, a positive trend has been detected in the last 19 years. The highest peak of occurrence was in 2016 (98 hotspots detected) and followed in 2003 (68 hotspots detected) (Figure 4).

Figure 4. Annual Hotspot based on land cover over Humbahas Regency

For the number of monthly hotspots analysis, it is seen that the spread of hotspots was mostly detected in February, June, and July (Figure 5). In February there were 67 hotspots. Whereas for June, the number of hotspots detected was 161 hotspots. A total of 147 hotspots were detected in July. Hotspots decrease in intensity in January (11 hotspots), April (4 hotspots), October (7 hotspots), November (1 hotspot), and December (5 hotspots) (Figure 5).
Referring to the results of the analysis of the number of hotspots per month in Humbahas, a comparison was made between the number of hotspots and the average monthly rainfall for 19 years based on the TRMM rain satellite in 3 districts namely Pollung, Doloksanggul, and Lintong Nihuta. The analysis shows that the detected hotspots have the same pattern as the average rainfall in Humbahas Regency. When rainfall is low, the more hotspots are detected and vice versa when the rainfall is high, the hotspots tend to decrease (Figure 6).

4. Discussion
Spatial analysis of hotspots has been carried out for Humbahas Regency. The spatial pattern of hotspots in Humbahas is spatially centered in two districts, namely Pollung and Doloksanggul. Based on Sitanggang et al. (2013), these two districts have natural resource potential in the form of peatlands [7]. In addition to the Lintong Nihuta sub-district. From the spatial map of the distribution of hotspots (figure 2), hotspots in Humbahas District were detected a lot, especially in sub-districts classified as peatlands such as in Pollung and Doloksanggul sub-districts. For the Doloksanggul sub-district,
several villages have quite several hotspots such as Hutaraja (23 points), Saitnihuta (15 points), and Simangaronsang (14 points). As for the Pollung sub-district, three villages have the highest records for hotspots, namely Parsingguran I (16 points), Parsingguran II (31 points), and Ria Ria (22 points).

Based on the overlay results with the 2011 land cover map from Bakosurtanal, some hotspots detected in Humbahas District indicated a lot to appear in dryland agriculture, dryland farming mixed with bushes and open land. For Humbahas, conditions with a high fire risk can be seen from the number of hotspots detected, especially in areas with potential peatlands. A hotspot is a pixel in a satellite portrait that is a representation of an actual area on earth covering an area of 1.1 km² and which has a temperature above 42°C [8]. When a hotspot is detected at a location, the surface temperature at that location reaches 42°C and is prone to burning.

Usually, peatlands are not flammable because of their sponge-like nature, which absorbs and holds water optimally so that in the rainy and dry seasons, there is no difference in extreme conditions. However, if the condition of the peatland has begun to be disrupted as a result of land conversion or canal making, the ecological balance will be disrupted. In the dry season, peatlands will be very dry to a certain depth and flammable. Peat contains fuel (plant residues) below the surface, so that fire in peatlands slowly spreads beneath the surface of the soil and is difficult to detect and causes thick smoke. Fire on peatlands is challenging to extinguish so that it can last for months (months).

Temporal analysis of hotspots in Humbahas District shows a positive Trend that indicates an increase in the number of hotspots detected each year. Based on temporal analysis of the number of monthly hotspots, many hotspots were detected in February, June, and July. Comparing the monthly pattern with average rainfall in Doloksanggul, Pollung, and Lintong Nihuta sub-districts shows a correlation between decreasing rainfall and an increasing number of hotspots detected. In general, hotspots will be detected if the surface temperature reaches 42°C. In this case, it is clearly seen that more hotspots will be detected due to rising surface temperatures during the dry season. In this case, the real cause of the temperature rises at a location identified by the hot spot must be studied more deeply. The increase in the number of hotspots, which is inversely proportional to the average rainfall, only gives the idea that the dry season (dry season) indicates an increase in the number of hotspots.

The increase in the number of hotspots can be used as reference information to conduct a direct inspection in the field to see whether the temperature rise is related to forest fires or only because it is purely an increase in temperature. The cause of rising temperatures in a location can only be known by direct observation in the field. There are two factors related to the changes in temperature, namely natural factors and human factors (anthropogenic). Natural factors include changes in local microclimates, such as drought. Human factors include human intervention in the process of increasing ambient temperature, such as the burning of forest/land, factory roof, and burning of waste. The land burn system can be one of the scapegoats of rising hot spots in the Humbahas during the dry season because, during the dry season, farmers are encouraged to burn land.

5. Conclusions
Spatially, most hotspots distribution in Humbahas Regency occurred in the eastern part of the Humbahas Regency, such as the Doloksanggul and Pollung sub-district. Besides, areas with peatland potential tend to have more hotspots. Hotspots in Humbahas Regency were detected on land cover in the form of dryland agriculture, dryland agriculture with bushes, and open land. Temporally, many hotspots are detected, especially in the dry months such as February, June, and July. Conversely, hotspots will decrease in intensity when entering wet months such as January, October, November, and December. A comparison of the number of hotspots to monthly average rainfall shows an inverse relationship between the two. When rainfall increases, the number of hotspots detected will decrease, and vice versa. For further study, the validation needs to be done directly to the field, especially about the truth of the detection of hotspots by MODIS satellites.
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