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Evaluation Of Hotspots Based on Climate Data in The Nagan Raya Regency, Aceh

Abdurahman[1,2], Nazli Ismail[1], Faisal Abdullah[1*], I Dewa Gede Arya Putra[3]

[1]*Department of Physics, Faculty of Mathematics and Natural Sciences, University Syiah Kuala, Aceh, Indonesia*
[2]*Aceh Besar Climatological Station, Indonesian Agency for Meteorology, Climatology, and Geophysics*
[3]*Research and Development Center, Indonesian Agency for Meteorology, Climatology and Geophysics*

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Corresponding Author
E-mail: faisal@unsyiah.ac.id

ABSTRACT

Identifying hotspots as a potential for wildfires due to weather/climate factors needs to be studied in more detail to consider the policies taken by relevant agencies in the Nagan Raya Regency, mainly consisting of peatlands. Rainfall observation data in some areas are incomplete, so alternative data are needed for rainfall estimation for those areas, such as satellite data. However, the satellite data does not necessarily match the conditions in the field, so validation is needed. In this study, satellite data were validated with available observational data in the area, so the results can be used as a reference when field data is unavailable. The data used are GSMaP_GNRT6 and observation data from 5 rainfall observation posts: Beutong, Cut Nyak Dien Meteorological Station, Darul Makmur, PT. Socfindo and Pulo Ie for the period 2010-2019. The satellite and the observation data were correlated with the Pearson method to see the relationship between the two data. The difference between each satellite data and observations at the same time and place is calculated using the formulas Mean Error (ME), Root Mean Square Error (RMSE) and Mean Absolute Error (MAE).
Furthermore, a case study of fire incidents and satellite hotspot data at several locations was also observed simultaneously. In addition, the validated rainfall data were also used to calculate the Standardized Precipitation Index (SPI) value. The result shows the validation of rainfall data with GSMaP_GNRT6 satellite data has a moderate correlation with the MAE value ranging from 101.3 to 195.12 from the five rainfall observation posts. The results also show that a 10-day base of rainfall before the occurrence of the wildfires was in a low category (86%). The number of hotspot occurrences was also supported by the negative monthly SPI value, high air temperature, and the type of land in the study area.

INTRODUCTION

Based on the Regulation of the Minister of Forestry Number 12 of 2009, a forest fire is a condition where the forest is hit by fire, causing damage to the woods and forest products, causing economic loss and decreasing environmental value (Yuniastuti et al., 2018). The number and rate of forest fires in an area are driven by various factors, including weather conditions, degraded land, human activities (Budiningsih, 2017), prolonged dry season (Nuryanto, 2015), volcanic eruption (Ismail et al., 2019) and climate change (Fried et al., 2008; Julismin, 2013). According to the Presidential Instruction of the Republic of Indonesia Number 11 of 2015, carrying out prevention activities is one of the strategies that can be applied to improve forest and land fire control. Identification of forest and land fire potential can be noticed from hotspot occurrence.

The hotspot occurrence is depended on the type of land and the amount of rainfall in an area. Rainfall and its anomalies, such as El Nino and a prolonged limited amount of rainfall, are significant indicators that triggered land fires in Indonesia (Ceccato et al., 2010). According to (Yananto & Dewi, 2016), when a strong El Nino occurred in 2015, which prolonged the dry season, the number of hotspots in the same year was considered the highest number of hotspots in Kalimantan and Sumatra in the last ten years. The highest numbers of hotspots usually occur at the peak of a dry season (Putra et al., 2018).

According to World Meteorological Organization (WMO) & Global Water Partnership, 2016), monitoring and early warning of drought are possibly done using one or more indicators or indices. The simplest indicators or indices frequently implemented are operationally generated and freely available products. However, it still cannot be concluded that those are the most effective strategies to be implemented. One of the easiest meteorological drought indices that can be used is the Standardized Precipitation Index (SPI). These indices are calculated based on the drought and frequency relationship, duration and time scale. In 2009, WMO recommended that a country apply the SPI as a significant meteorological drought index to monitor its drought conditions (Hayes et al., 2011).

Therefore, Aceh Province has a Seasonal Zone (ZOM) and a Non-Seasonal Zone (Non-ZOM). Nagan Raya Regency is a non-ZOM area due to none of the specific boundaries between rainy and dry seasons. Consequently, the potential of wildfires caused by climatic factors in this area is more challenging to determine. Moreover, there are Peat Protected Areas in Nagan Raya Regency, about 11. 380,71 ha located in Darul Makmur District (Qanun, 2015). During the dry season, the peat surface is quickly dried and quite flammable so that the fires on the surface can spread to the relatively moist lower layers (Dahlia et al., 2019; Rasyid, 2014). That fire condition mixed with water vapour in the peat area leads to smog generation (Adinugroho et al., 2005). However, weather observation data such as rainfall and air temperature collected every hour at Cut Nyak Dien Meteorological Station needs to be further processed to provide climate information for Nagan Raya Regency to anticipate the hotspot occurrences. This research aims to analyze the emergence of hotspots by utilizing weather and climate observations data available for area of Nagan Raya Regency.

RESEARCH METHODS

A variety of data used in this research consist of hotspot data acquired from Moderate Resolution Imaging Spectroradiometer (MODIS) sensors of the Terra and Aqua satellites, weather observations data from Cut Nyak Dien Meteorological Station, rainfall observation data obtained from nearby five rainfall observation posts namely Beutong, Cut Nyak Dien Meteorological Station, Darul Makmur, PT. Socfindo and Pulo Ie for the period of 2010-2019, daily precipitation from Global Satellite Mapping of Precipitation Near-real-time Gauge-adjusted Rainfall Product version 6 (GSMaP_GNRT6) with 0,1° x 0,1° spatial resolution, and wildfires data occurred in Nagan Raya Regency from Aceh Disaster Management Agency (BPBA) as shown in detail in Table 1. All of the data used in this research are secondary. The weather observation data is technical data that is observed every hour by observers of the Cut Nyak Dien Meteorological Station. The meteorological data were collected by the Aceh Climatology Station in Indrapuri as the coordinator of climate data in Aceh Province so that the data can be acknowledged as valid data.

This research implemented the descriptive analysis method to explain the relationship of the parameters used in this study. Processed data of air temperature, humidity, rainfall observation, and GSMaP_GNRT6 satellite imagery were used to support the analysis of hotspot emergence in particular months. Weather or climate data such as air temperature, humidity, and sunshine duration of the study was obtained from Cut Nyak Dien Meteorological Station. In contrast, rainfall data were obtained from

5 rainfall observation posts: Beutong, Cut Nyak Dien Meteorological Station, and Darul Makmur, PT. Socfindo and Pulo Ie for the period of 2010 - 2019.

Table 1. Various data that were used in this research

Data	Period	Source
Hotspot	2010-2019	https://firms.modaps.eosdis.nasa.gov/
Air Temperature	2010-2019	Aceh Climatology Station (BMKG)
Precipitation	2010-2019	Aceh Climatology Station (BMKG)
GSMaP	2010-2019	ftp://hokusai.eorc.jaxa.jp
Wildfires	2014-2019	Aceh Disaster Management Agency (BPBA)

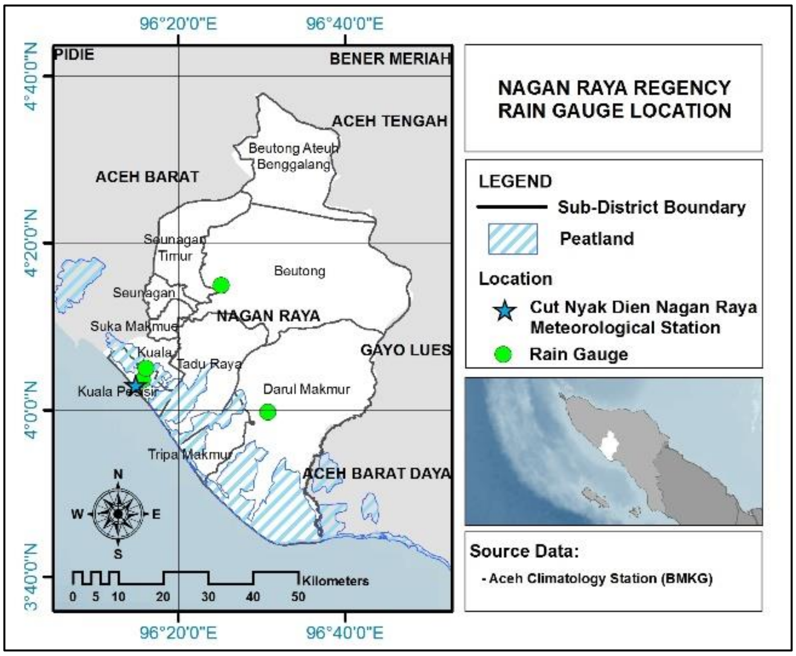

Figure 1. Research area

Constraints that are often encountered in the analysis and prediction of rainfall are the lack of availability of observational rainfall data both spatially and temporally, the time series of rain data is not long enough and incomplete, and the number of rain stations is not evenly distributed (Su et al., 2008), the lack of human resources or observers, the observation and data entry system is still manual, data collection from specific regions to the central level is still slow, and the data format is not standardized. Therefore, an alternative method of estimating rainfall is needed to overcome the limitations of the observational rainfall data. One alternative that can be used is rain satellite data, especially in areas where rainfall observation data are scarce (Mamenun et al., 2014) or unavailable. However, the rain satellite data does not necessarily match the conditions in the field, so a validation process is needed. This research used The GSMaP_GNRT6 satellite data. The validation processes were carried out by comparing the estimated rain satellite data with the observational rainfall data from 5 rainfall measurement posts in the study area. Validation techniques that can be applied consist of Mean Error (ME), Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and the Pearson correlation method.

In addition, the Standardized Precipitation Index (SPI) value was also calculated to support the analysis of wildfire events. (WMO, 2012) claims that the SPI is designed to calculate rainfall deficit for multiple time scales. This time scale represents the drought impact on fount availability (Nugroho et al., 2021). Soil moisture condition responds to rainfall anomalies on a relatively short scale. A 1-monthly SPI map is closely similar to a map representing a standard rainfall percentage of 30 days. The derived SPI value represents monthly rainfall in more accurate data due to its normalization distribution. (Salehnia et al., 2017) argue that SPI is calculated based on gamma distribution defined as frequency function or occurrence chance. The formulation is written as follows:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} \; (x > 0) \; (1)$$

In description: Γ(α) is gamma function, x is precipitation numbers (rainfall in millimetre), α is parameters form of (α>0), and β is scale parameters of (β>0). SPI has an intensity scale calculation of positive and negative values directly correlated with wet and dry events. SPI value classification can be seen in Table 2.

Table 2. SPI Value

Value	Category
≥ 2.0	Extremely Wet
1.5 – 1.99	Very Wet
1.0 – 1.49	Moderately Wet
-0.99 – (0.99)	Near Normal
-1.0 – (-1.49)	Moderately Dry
-1.5 – (-1.99)	Severely Dry
≤ - 2.0	Extremely Dry

Source: WMO, 2012.

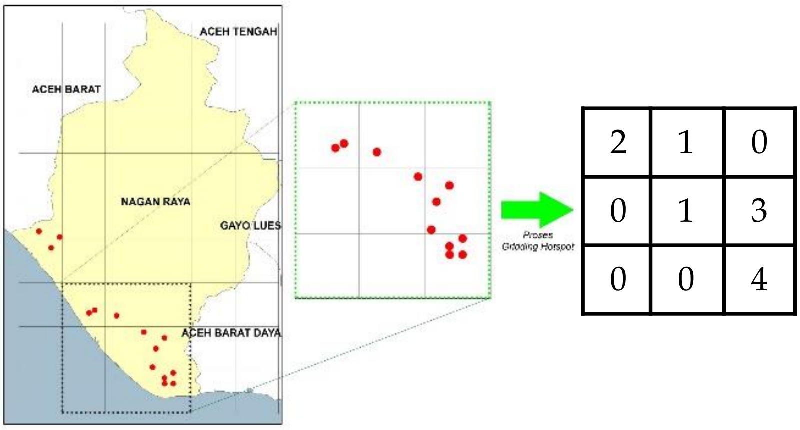

Figure 2. Illustration of hotspot gridding process

Hotspot data analysis was conducted by processing the data spatially and temporally. Hotspot data visualization was carried out as described in (Putra et al., 2018) through several data processing stages, one of which was a gridding process. Figure 2 represents a hotspot gridding process illustration in Nagan Raya Regency with 10 x 10 km resolution. Monthly hotspot grid output was saved in NetCDF file format. Hotspot analysis from MODIS data used seven spectrums of electromagnetic waves, namely 4 μm thermal spectrums, 11 μm and 12 μm, and 0.65 μm reflectance spectrums, 0.86 μm and 2.1 μm. The use of each channel can be seen in Table 3.

The horizontal accuracy level of determining hotspot coordinates from satellite data is about 1 km to 2 km (Vetrita & Haryani, 2012; Zubaidah et al., 2014). This is due to the spatial resolution of the satellite images, both NOAA and Terra/Aqua MODIS, which is 1 km x 1 km in the centre of the picture. At the same time, the spatial resolution on the edge of the image can reach 2 km x 2 km so that the horizontal accuracy of the hotspot location can reach a maximum of 2 km. According to (Rahadian et al., 2016; Zahrotunisa et al., 2022), the distribution of hotspot locations on NOAA-18/AVHRR and Aqua MODIS mod14 satellite imagery shows that large areas with high-temperature intensity are indicated as fire-prone areas.

Table 3. MODIS channel for hotspot analysis

No Channel	Central Wavelength (µm)	Purpose
1	0.65	Sun glint and coastal false alarm rejection; cloud masking.
2	0.86	Bright surface, sun glint, and coastal false alarm rejection; cloud masking.
7	2.1	Sun glint and coastal false alarm rejection.
21	4.0	High-range channel for active fire detection
22	4.0	Low-range channel for active fire detection
31	11.0	Active fire detection, cloud masking, forest clearing rejection.
32	12.0	Cloud masking.

Source: Giglio et al., 2016.

RESULTS AND DISCUSSION

GSMaP_GNRT6 Satellite Validation

The distribution of rainfall estimation data from satellites and monthly observation data has a linear relationship, as shown by the scatter plot of monthly rainfall in Figure 3. The frequency of rainfall estimation data from GSMaP_GNRT6 satellite data in a certain range is close to the value of the observation data. Its condition showed that the satellite data was proper enough to be applied for a monthly duration. This shows that satellite data is good enough to use monthly time scales. Monthly rainfall measurement data from 5 locations of rainfall measurement posts (Table 4) shows data from measurement posts at PT. Socfindo shows the lowest coefficient of determination, while data from the Darul Makmur measurement post shows the highest coefficient. The difference between satellite rainfall data and observation data ranges from -18.49 to -174.06 mm, which explains that the GSMaP_GNRT6 rainfall estimate value has a lower average value than the observation data. The value of the coefficient of determination of monthly rainfall from the location of the Beutong rain post, Cut Nyak Dien Meteorological Station, Darul Makmur, PT. Socfindo and Pulo Ie were 0.60, 0.64, 0.65, 0.53 and 0.56, respectively. These results show that the correlation of GSMaP_GNRT6 monthly rainfall estimation data with observational rainfall data has a medium correlation value for five observation locations.

Based on the results of processing monthly rainfall data, observation data and GSMaP_GNRT6 satellite data, the rain pattern in the study area is an equatorial pattern. This is following the results obtained by (Aldrian & Susanto, 2003) that the tropical rainfall pattern has two peaks, namely in October-November (ON) and March-May (MAM). Rainfall estimation data from the GSMaP_GNRT6 satellite is overestimated compared to data from the Beutong rain post location, which is at 100 meters. However, the rainfall data is underestimated compared to data from 4 other rain post locations at low elevations. Therefore, for a time scale of 10 days, rain gauge locations with low hills such as Cut Nyak Dien Meteorological Station, Pulo Ie and PT. Socfindo rain post has a smaller error value than the Beutong location, and the correlation value is moderate, ranging from 0.52 to 0.63. This follows the research of (Kubota et al., 2007) that the correlation results and the Heidke skill score (HSS) are best above sea level and worst above ground level.

Table 4 also explains the validation results between the GSMaP_GNRT6 rainfall prediction data and the ten days time scale and monthly rainfall observations data in Nagan Raya Regency. Predicted rainfall at the Beutong rain post location had the highest ME, RMSE, and MAE values. The correlation coefficient at five observation locations was in the medium category.

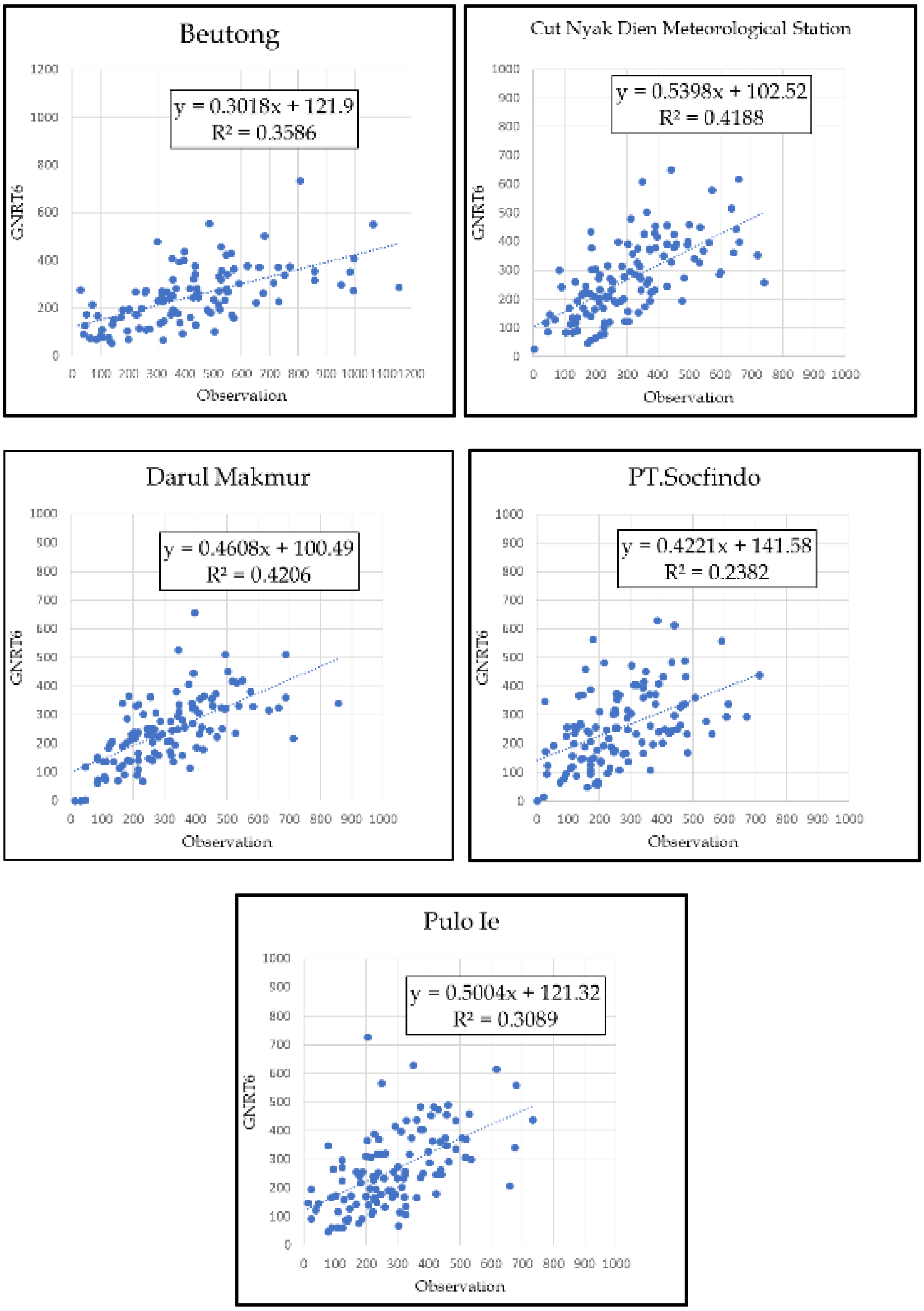

Figure 3. Scatter plot of monthly rainfall in Nagan Raya Regency

Table 4. 10-days and monthly data validation of GSMaP_GNRT6 satellite

Station/ Rain Gauge	10-days				Monthly			
	ME	RMSE	MAE	CC	ME	RMSE	MAE	CC
Beutong	-59.10	79.85	112.16	0.52	-174,06	195,12	261,18	0,60
Stasiun Meteorologi Cut Nyak Dien	-22.99	52.95	72.92	0.57	-49,02	102,66	134,56	0,64
Darul Makmur	-6.17	50.61	71.28	0.52	-67,57	106,70	142,53	0,65
PT. Socfindo	-7.50	51.03	68.86	0.54	-18,49	101,32	130,77	0,53
Pulo Ie	-15.66	49.66	70.90	0.63	-22,49	106,41	137,82	0,56

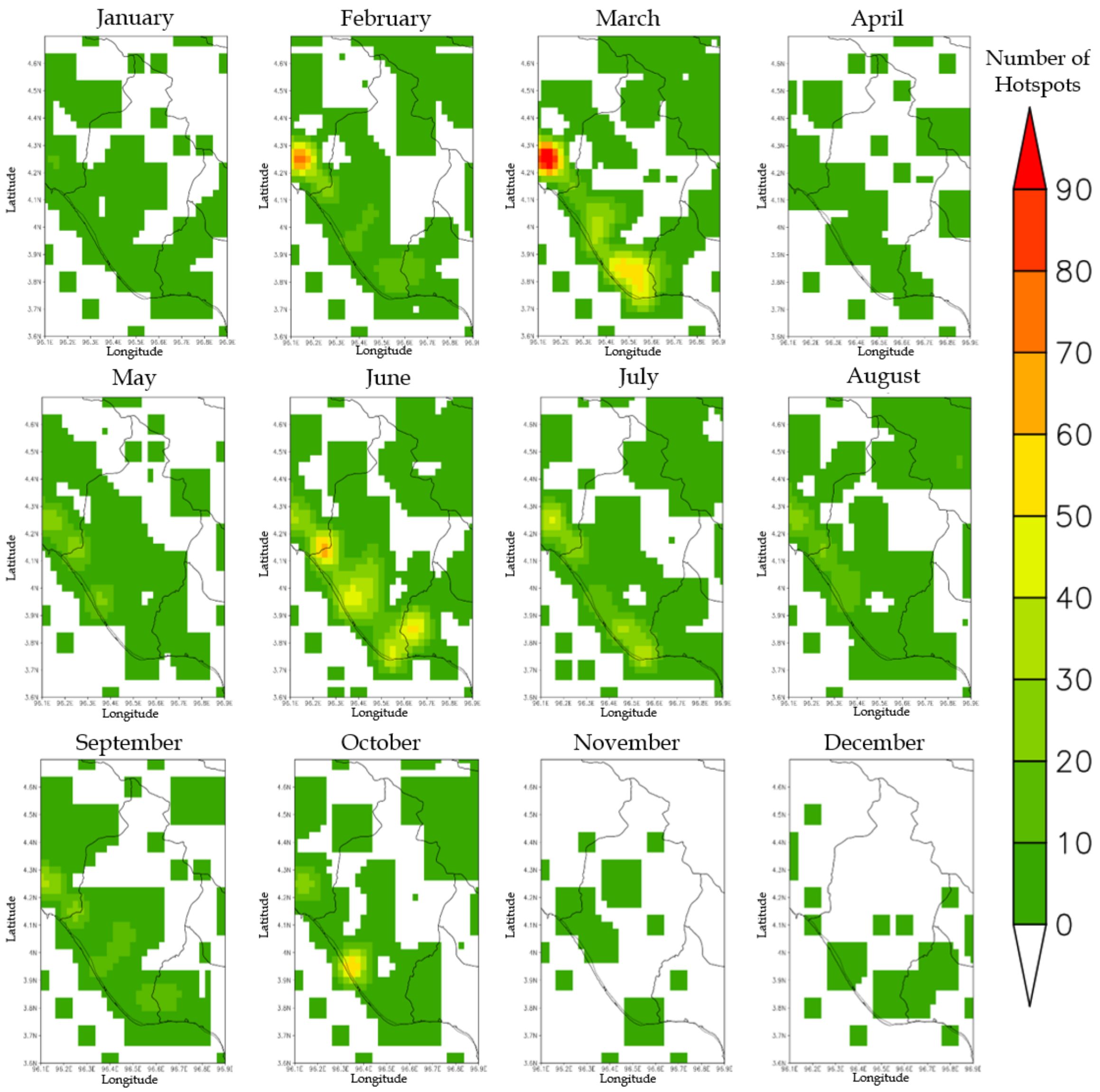

Figure 4. The number of MODIS hotspots year 2010-2019 every month

Hotspot Identification

Figure 4 shows that the number of hotspots increased in the middle of the year, around June, due to a lack of rainfall and high air temperatures. The hot spots were primarily found in the Darul Makmur, Tripa Makmur, and Tadu Raya districts. Figure 5 presents the monthly hotspots in each sub-district in Nagan Raya Regency. In addition to the weather factors above, the emergence of this hotspot is also influenced by the type of soil in the area. According to research by (Sari and Fildes, 2017), the results of the classification of object-based map analysis (OBIA) using SPOT-6 imagery indicate that areas in the southern part of Darul Makmur, Tadu Raya and Tripa Makmur District have a large area of peat swamp lands and oil palm plantations.

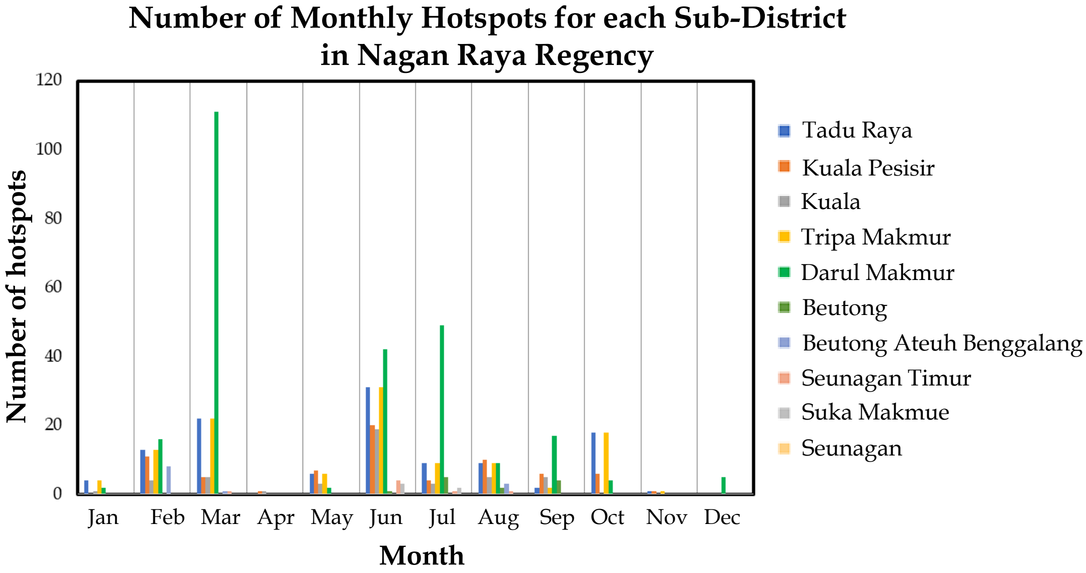

Figure 5. Hotspots numbers in each sub-districts of Nagan Raya Regency

Weather Observation Data

Low rainfall and high air temperature positively affected the number of hotspots (Putra, Hayasaka, Takahashi, & Usup, 2008). The average air temperature recorded at Cut Nyak Dien Nagan Raya Meteorological Station ranges from 25.3° – 28.0°C, with the highest average maximum air temperature, which was 31.9°C. However, the rainfall data year 2010 to 2019 described that the lowest average rainfall was from June to July. The maximum air temperature data in the extreme category year 2010 to 2019 was recorded 11 times. Extreme air temperature is an air condition reaching 3ºC or more local standard value (BMKG, 2010). The powerful category of air temperature occurred in 2015 (October and November), 2016 (February, March, and July) and 2019 (March, June, and July).

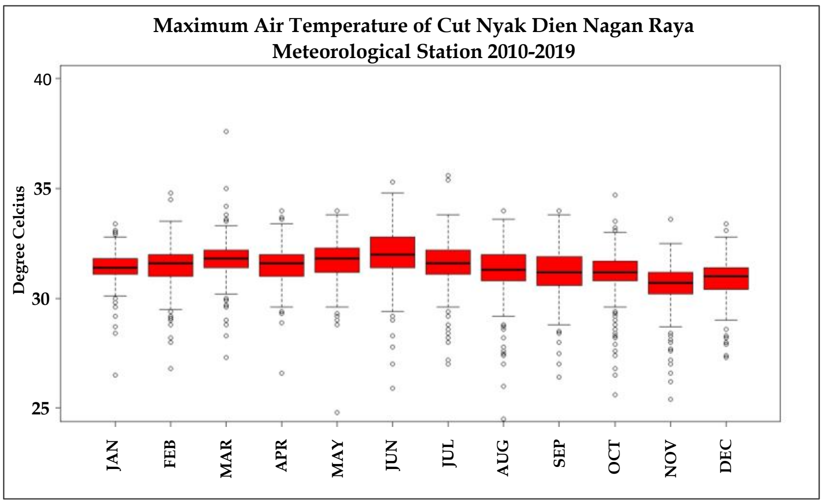

Figure 6. Plot box of daily maximum air temperature at Cut Nyak Dien Nagan Raya Meteorological Station year 2010 to 2019

Figure 6 presents a plot box of daily maximum air temperature data from Cut Nyak Dien Nagan Raya Meteorological Station from 2010 to 2019. The highest median value of 32.0°C was in June. It happened because of sun's position on the moon was in the north equator area, hence the solar radiation intensity that reached the earth's surface was more intense compared to other months (Zahrotunisa et al., 2022). On the other hand, the lowest median value of 30.7°C was in November, this condition was due to the higher rainfall at the end of the year, and it affected the average maximum air temperature at Cut Nyak Dien Nagan Raya Meteorological Station.

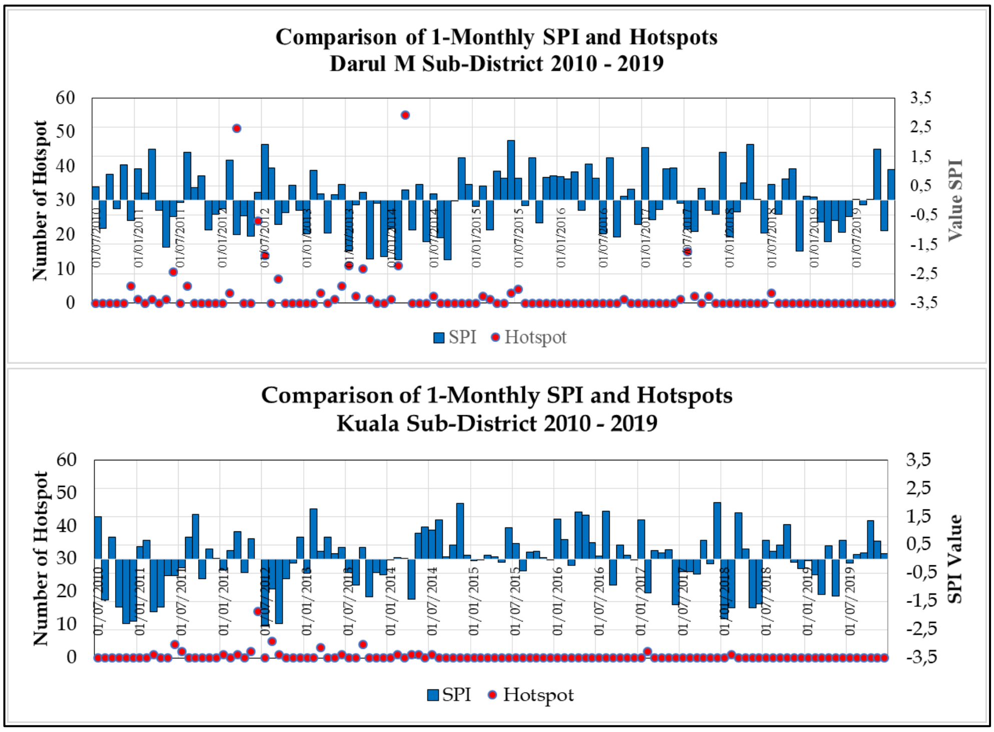

Figure 7. Graph of 1-monthly SPI time series and the number of location hotspots in Darul Makmur and Kuala

Figure 7 represents a graph of monthly SPI data processing results in Darul Makmur and Kuala. The El Nino phenomenon, which occurred from 2015 to 2016, did not show a negative monthly SPI value; the identified number of hotspots in the Kuala and Darul Makmur sub-districts was less than ten occurrences.

Forest and Land Fires

Forest and land fire identification by using hotspot data needed to be considered in more detail (Setiawan et al., 2017). Figure 8 describes 4 cases of forest and land fires that occurred in Nagan Raya Regency year 2018. Forest or land fires of 20 hectares that occurred in Kuala Semayam village, Darul Makmur sub-district, were recorded on July 3, 2018. Hotspot first existed on July 3, 2018, at night with a 100% confidence level. Furthermore, hotspots were still detected on July 4, 2018, with moderate to high confidence spared around the fire incident location. This case was supported by the characteristics of clustered hotspots or repeated occurrences: it was confirmed that forest or land fires occurred (Page & Hooijer, 2016; Yusuf et al., 2019).

Other wildfires in Gampong Suak Puntong, Kuala Pesisir sub-district, and Alue Siron village, Tadu Raya sub-district occurred the same day. A wildfire at Gampong Suak Puntong village on July 3, 2018, was recorded at 10 hectares. The MODIS Aqua satellite detected the hotspot on July 2, 2018, with a 67% confidence level.

Hotspots were not detected on July 3, but they appeared in four locations on July 4 with 44%– 66% confidence level ranges. Moreover, forest or land fires of 6 hectares area also occurred at Gampong Alue Siron on July 3, 2018, but the MODIS Aqua or Terra satellite did not record any hotspots.

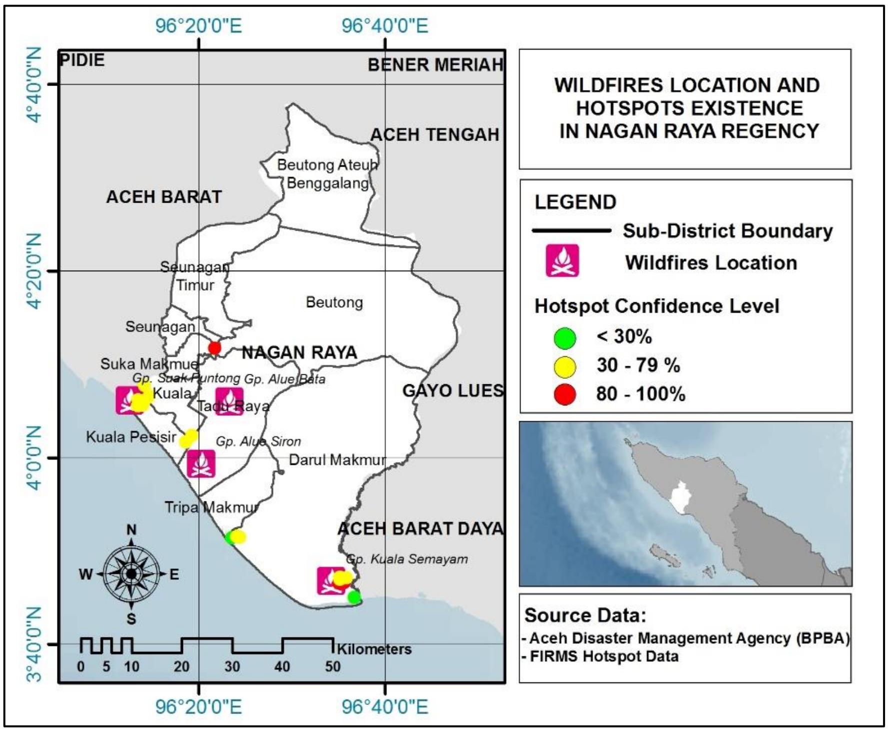

Figure 8. Wildfires location and hotspots (MODIS) existence in Nagan Raya Regency year 2018

According to 2017 to 2019 data, 14 forest or land fires were evaluated based on climatic factors. Rainfall observation data applied to evaluate fire occurrences were taken from the rainfall data from the closest location. Essential rainfall on a day before the forest or land fire in the low category (0 – 50 mm) occurred at around 86%, in the medium type (51 – 150 mm) occurred at about 7%, and in the high category (150 – 300 mm) around 7%, in the highest category (>300 mm) around 0%. The rainfall values percentage according to the primary rain category can be seen in Figure 9.

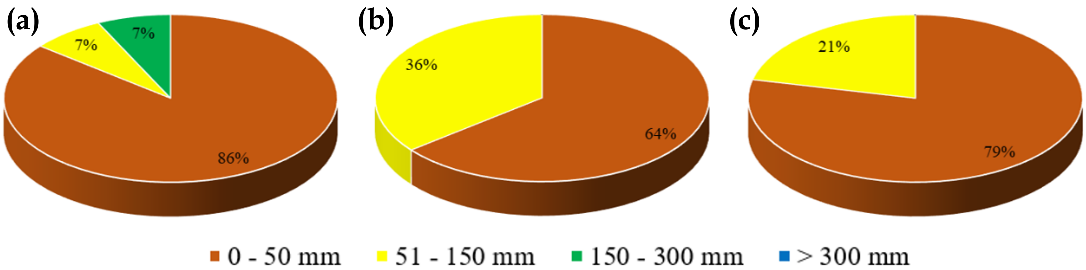

Figure 9. Rainfall percentage before wildfires occurrence
(a) 10 Days (b) 11-20 Days (c) 21-30 Days

CONCLUSION

Forest or land fires could be identified using weather elements such as rainfall and temperature. The limitation of rain observation data in Nagan Raya Regency could be solved using the GSMaP_GNRT6 satellite rainfall prediction data, even though it had a medium correlation value on a 10-daily and monthly scale. To obtain better results, it may be necessary to calculate a correction factor for the GSMaP_GNRT6 satellite rainfall estimation data. About the forest and land fires in Nagan Raya Regency, 86% of the rainfall one month before the occurrence of forest and land fires was in a low category (0-50 mm). This affects the increase in the number of hotspots. In addition, the calculation results of the negative one-month SPI value, high air temperature, and the type of peat land in the Nagan Raya Regency area also support the formation of hotspots.

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