Analysis of drought index to assess land and forest fire season in Maros Regency

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Abstract. Forest and land fires occur almost every year, so they are a concern and priority in their control efforts. One of the important factors in the effort to control forest and land fires is knowing the times and locations that are prone to forest and land fires. This study aims to describe the level of drought and areas prone to forest and land fires in Maros Regency, South Sulawesi. This research was conducted in January to August 2017. The data collection was obtained from the Meteorology, Climatology and Geophysics Agency, the Climate Change Control Center, and the Bantimurung Bulusaraung National Park. The data were analyzed using the Polygon Thiessen method, the Keetch Byram Drought Index (KBDI) method, and the spatial analysis method. The results showed that extreme drought conditions in Maros Regency occurred from September to October based on observations of maximum rainfall and temperature. The forest area classified as moderate forest fire danger rating dominates the Maros Regency area, namely 73418.67 ha (45.77%). Maros Regency which is included in the area with a very high forest fire danger rating is Tompobulu and Cenrana Districts.

1. Introduction

Fire is one of the main causes of forest ecosystem degradation worldwide both naturally and anthropogenic [1,2]. Forest fires are still a problem in Indonesia because the losses caused are very large. The losses incurred are in the form of damage to soil ecology, hydrological systems, land degradation and soil erosion [3], economic losses, increased pests, air pollution due to fire smoke that causes respiratory infections and decreased forest and land productivity [4].

The causes of forest fires can be distinguished by two factors: natural and human factors. Natural factors are related to climate, land conditions and fuel sources. Fires caused by human factors can occur intentionally (forest burning) or unintentionally (element of intent). According to [5], more than 90% of forest and land fires in Indonesia are caused by humans. Human caused forest fires are a form of deforestation that has occurred recently. Another cause of deforestation is illegal logging activities which result in increased surface runoff, interception, infiltration and decreased evaporation causing air temperatures to increase and the risk of forest fires will be greater [6].

Factors that influence the triggering of forest fires or commonly called the fire triangle are fuel, oxygen, and triggers. These three factors, the thing that can be manipulated (treated) is fuel. Conditions where the fuel is moist with high rainfall makes it difficult for fires to spread to other places. Simioni et
al. 2020 also reported that extreme climate change could exacerbate fire-induced ecosystem damage such as decreased rainfall and increased temperatures [7].

Maros Regency is one of the areas that has a record of forest and land fires occurring every year. The incidence of forest fires in Maros Regency in the period 2012-2016 at the Bantimurung Bulusaraung National Park was reported that the forest area that had been burned was around 156,058 ha. Data from the Regional Disaster Management Agency of Maros Regency (2015) notes that forest fires occurred in 2014 in Tompobulu District and in 2015 simultaneously in three points, namely Simbang District, Hasanuddin University Education Forest and Karaenta Maros Nature Reserve Area located in Cenrana District.

The forest fire hazard rating (fire danger rating) is a fire management system that is adjusted or integrated with the influence or consequences of fire hazard factors which are expressed in one or more qualitative values or index values for the need for control methods [8]. The Keect Byram Drought Index (KBDI) method shows the level of flammability of a soil organic material. These organic materials are found in the forest in the form of humus, buried wood, and other organic materials on the forest soil floor. This method helps to assess the duration of the pattern of drought conditions by referring to rainfall and daily maximum air temperature [9].

The distribution of drought conditions uses the polygon Thiessen method which is intended for areas that are not uniform and have large variations in rainfall, such as in Maros Regency. The suitability of land cover to conditions that are able to support the occurrence of fires is an important parameter in knowing the potential for fuel, so the spatial analysis method is used. Spatial analysis determines the scoring and weighting of the parameters of land cover, slope, slope direction, road distance, and residential distance that support the emergence of hotspots, spread, and intensity of fires that will occur. Observations using some of these methods can assist in fire control operations in Maros Regency to predict, monitor, identify and assess the level of fire hazard.

This study aims to assess the level of forest fire hazard based on the KBDI method in Maros Regency and to map forest fire-prone areas in Maros Regency.

2. Materials and methods

2.1. Tools and objects

Tools used in this research are tools used in this research are (1) Global Positioning System (GPS) is used to take the coordinates of the location of the rainfall captive station; (2) Stationery is used to record observation data; (3) Camera to documenting research activities; (4) Laptops are used for processing spatial data on ArcGIS 10.1 and Ms. Excel 2007.

Materials needed in the form of data to support this research are administrative area map, land cover map, slope map and slope direction, road and settlement accessibility map in Maros Regency in 2016. As well as to assess KBDI required climate data, namely temperature maximum air and daily rainfall for the period 2007 to 2016, data on the location of forest fires at the Bantimurung Bulusaraung National Park Center and the PPI (Climate Change Control) Center.

2.2. Research methods

The working procedure carried out in this study is data analysis by dividing the distribution of rainfall using the polygon Thissen method as many as 14 rainfall measuring stations in the Maros Regency. Calculated daily maximum rainfall and temperature from 2007 to 2016 to assess drought using the KBDI method adjusted to the distribution area of polygons Thissen. This method results in the drought time of the distribution area of the rainfall measuring station.

Spatial analysis includes data on land cover, slope, slope direction, road distance and residential distance as factors that trigger forest and land fires in Maros Regency. Calculations were made from the established scoring and weighting and made a vulnerability class using the Sturges formula for the Maros Regency [10].
2.2.1. **Polygon Thiessen Method.** Polygon Thiessen method is polygon processed in the program tool ArcGIS 10. Connecting the points where the nearest station is on the Maros Regency map with a straight line. Forming lines connecting station points and calculating the area of each station.

2.2.2. **KBDI Method.** To obtain the drought factor obtained using the following formula Keech and Byram (1988) quoted by [11]:

\[
FK = \frac{(2000 - \text{KBDI}_Y) \times (0.967^{(0.0875 \times T_{\text{max}} + 1.552) - 0.299})}{1.0 + 10.88^{(-0.00175 \times R)}} \times 0.001
\]

Note:
- FK: drought factor
- KBDIY: Keech-Byram drought index yesterday
- Tmax: Maximum air temperature (°C)
- R: Average Annual Rainfall (mm)

Calculate the KBDI value in processing drought index data to measure the level of fire hazard using the Keech and Byram formulations as follows:

\[
\text{KBDIT} = (\Sigma \text{KBDI}_Y - 10 \times \text{Ch}_\text{net}) + \text{FKT}
\]

Note:
- KBDIT: Today's drought index
- KBDIY: Yesterday's drought index
- Ch_net: Nett rainfall
- FKT: Today's drought factor

Classification of the KBDI value range into four sub-ranges. Each sub-range shows a class of fire hazard properties which can be seen in Table 1.

| Numerical Scale | Properties Class |
|-----------------|-----------------|
| 0 – 999         | Low             |
| 1000 – 1499     | Medium (Moderate)|
| 1500 – 1749     | High            |
| 1750 – 2000     | Extreme         |

2.3. **GIS analysis**
This method is made with spatial analysis, to further simplify the process, the weighting and scoring formulas are used [12]. The formula and level of weighting and research scoring refers to the incorporation of the weighting classifications carried out by Suparni (2014) [10] and Miardini and Nunung (2013) [13] described in Table 2.

| Parameter                  | Class            | Weight | Factor |
|----------------------------|------------------|--------|--------|
| Cover Vegetation           | Thicket          | 7      | 7      |
|                            | Shrublands       | 6      |        |
|                            | Mangrove Primary | 2      |        |
|                            | Mangrove Forest Secondary | 3      |        |
|                            | Forest Dryland Primary | 4      |        |
Forest Dryland Secondary: 6
Plantation Forestry: 6
Plantation: 5
Dryland Agriculture: 7
Dryland Agriculture Mixed Shrubs: 5
Pond: 1
Open Land: 1
Mining: 2
Rice Fields: 4
Settlement: 7

| Slope   |   |   |
|---------|---|---|
| > 35%   | 5 | 5 |
| 25 – 35%|   | 4 |
| 10 – 25%|   | 3 |
| 5 – 10% |   | 2 |
| < 5%    |   | 1 |

| Aspect   |   |   |
|----------|---|---|
| South    | 5 | 5 |
| West     |   | 4 |
| East     |   | 3 |
| North    |   | 2 |

| Distance from the Road (Distance from road) |   |   |
|---------------------------------------------|---|---|
| < 100 m                                     | 3 | 5 |
| 100 – 200 m                                 |   | 4 |
| 200 – 300 m                                 |   | 3 |
| 300 – 400 m                                 |   | 2 |
| > 400 m                                     |   | 1 |

| Distance from Residential (Distance from settlements) |   |   |
|------------------------------------------------------|---|---|
| < 1,000 m                                            | 3 | 5 |
| 1,000 – 2,000 m                                      |   | 4 |
| 2,000 – 3,000 m                                      |   | 3 |
| > 3,000 m                                            |   | 2 |

Spasial analysis by combining land cover maps, slope direction maps, slope maps, settlement accessibility maps, and road accessibility maps in determining fire-prone areas using the method cited by [12] namely:

\[
RC = 7 \times VT + 5 \times (S + A) + 3 \times (DR + DS)
\]

Note:
RC : Vulnerable Zone
VT : Vegetation Type
S : Slope
A : Aspect
DR : Distance from Road
DS : Settlement Distance

The results of the spatial analysis of the vulnerability map in Maros Regency will produce 5 zoning classes based on the calculation results with the above formula. Determination of the number of classes and class intervals to determine the class of vulnerability used the Sturges formula, namely: [10].

\[
\text{Number of Classes} = 1 + 3.3 \log n
\]
\[
\text{Class Interval} = \frac{\text{Range}}{\text{Number of Classes}}
\]

Note:
Map of forest and land fire susceptibility level is composed of fire triggering factors and drought factors. Picture frame of the study from the summary of the methods and spatial analysis are shown in Figure 1.

3. Results and discussion

3.1. KBDI drought rate

Based on the parameters of rainfall and daily maximum air temperature, the results of KBDI are obtained. The drought level was obtained using the KBDI method which shows the effect of fuel conditions on the process of forest fires which is also related to time. The calculation of the daily drought index as shown in Figure 2 can be seen that droughts which indicate an extreme level of fire hazard (KBDI> 1750) are more common in August to October (Table 3). The index pattern that occurred during the last 10 years, generally occurred during the dry season because at that time the weather and climate conditions were very hot, so forest fuel would be very dry which caused forest fires. Research by [14] reported that weather conditions greatly affect the spread of fire, especially surface fires. Changes in weather, especially air temperature, are a very important reference for predicting the type and frequency of forest fires [15–20]. High air temperatures will reduce air humidity so that the risk of forest fires is greater, as happened in California [21]. In line with the research of [21] who reported that temperatures below 2°C in summer tripled the rate of fires in France.
The effect of rainfall on the high value of daily drought will decrease from November to December and continue in January of the following year until June or July. The Drought value will indicate the level of forest fire hazard and is very high when very low rainfall lasts a very long time.

Table 3. Results of Drought Intensity from the Average Value of KBDI per month that occurred in District Maros.

| Number | Month    | $\Sigma$ KBDI | intensity of drought |
|--------|----------|---------------|---------------------|
| 1      | January  | 265           | Low                 |
| 2      | February | 363           | Low                 |
| 3      | March    | 628           | Low                 |
| 4      | April    | 937           | Low                 |
| 5      | May      | 1224          | Moderate            |
| 6      | June     | 1518          | High                |
| 7      | July     | 1718          | High                |
| 8      | August   | 1901          | Extreme             |
| 9      | September| 1891          | Extreme             |
| 10     | October  | 1786          | Extreme             |
| 11     | November | 1306          | Moderate            |
| 12     | December | 575           | Low                 |

Table 4. Regional Forest Fire Reporting Bantimurung Bulusaraung Nasional Park.

| Month     | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|-----------|------|------|------|------|------|------|
| January   | 0    | 0    | 0    | 0    | 0    | 0    |
| February  | 0    | 0    | 0    | 0    | 0    | 0    |
| March     | 0    | 0    | 0    | 0    | 0    | 0    |
| April     | 0    | 0    | 0    | 0    | 0    | 0    |
| May       | 0    | 0    | 0    | 0    | 0    | 0    |
| June      | 0    | 0    | 0    | 0    | 0    | 0    |
| July      | 0    | 0    | 0    | 0    | 0    | 0    |
| August    | 1    | 1    | 1    | 3    | 0    | 1    |
| September | 0    | 1    | 3    | 8    | 5    | 2    |
| October   | 0    | 0    | 0    | 5    | 3    | 0    |
| November  | 0    | 0    | 1    | 0    | 0    | 0    |
| December  | 0    | 0    | 0    | 0    | 0    | 0    |

Data on forest fires obtained based on the month the forest fires took place can be seen in Table 4. Forest fires generally occur when the KBDI >1750 which indicates extreme drought intensity. The results of the KBDI calculations show that the extreme drought intensity that occurred in August to October is in accordance with the data on reporting forest fires in the Bantimurung Bulusaraung National Park area at that time. However, a very high daily KBDI value in certain months does not always indicate a fire in that month. This is because the number of days experiencing KBDI > 1750 does not last for a long time so that fires do not occur. The non-occurrence of fires when the KBDI value is very high may also be caused by the absence of reporting of fire incidents to local agencies related to fires. Data reporting forest fire in Maros regency in the area of Bantimurung Bulusaraung National Park presented in Table 4.

Calculation of the daily Keetch Byram drought index in the study area started from 7 January 2007 to 31 December 2016 at 13 stations namely Maros Climatology Station, Meteorology Station
Hasanuddin, Mandai Agricultural Extension Center, Bantimurung Agricultural Extension Center, Pattene Marusu, Moncongloe Agricultural Extension Center, Batubasi, Tompobulu Agricultural Extension Center, Mallawa Agricultural Extension Center Agricultural Extension Center, Tanralili, Kappang, Gateng Matenggi, and Kuncio. At the Cenrana Agricultural Extension Center Station, the calculation starts on February 1, 2007 until December 31, 2016. This is based on the initial requirements for calculating the KBDI, the results of [22] research which states that yesterday's Keect Byram Drought Index (KBDIY) was obtained from the drought index on the last day previous month. If data is not available, then the rainfall is summed for one week in a row so that the rainfall reaches a value of approximately 150-200 mm, and the drought index for that day is 0 (zero).

During the period 2007 to 2016 the 14 rainfall measuring stations experienced an average index of the annual KBDI pattern with a low level of danger occurring in January – April and December. For a moderate level of danger takes place in May and November. This is because these months are wet months with high rainfall and low maximum temperatures. Unlike in June-July, the graph shows the KDBI value rose above 1500 to 1749 which indicates a high level of danger and began to decline in November. In August-October with the extreme hazard level (KBDI > 1750) which is almost evenly distributed throughout the year in that month, it indicates that the area (research area) is in dry condition.

![Graph of the average daily KBDI for the period 2007 to 2016.](image)

KBDI in Figure 2 shows the value of 2000 describing absolutely no soil moisture, so that if the soil is dry, of course there is not enough carrying capacity to grow plants on it. As a result, with dry soil and vegetation conditions supported by low rainfall and high temperatures, the supply of fire fuel becomes greater in the month obtained. This condition can support the assumption that hotspots will easily appear if drought conditions increase.

The factor determining the level of hazard from low to extreme is based on the rate of moisture loss in the forest area which will depend on the density of vegetation covering the area. The density of vegetation cover has an impact on its evaporation capacity, which is a function of the average value of annual rainfall. The rate of moisture loss decreases with a decrease in vegetation density, and with a decrease in the average annual rainfall. In addition to vegetation density and weather, vegetation composition is also a predictor of fire size [14,23].

On an annual basis, the KBDI in Maros Regency in 2009, 2014, 2015 had the longest and highest levels of extreme danger compared to the previous year, this is likely due to the El Nino phenomenon or monsoon nature. El Nino is a natural phenomenon characterized by an unnatural warming of ocean temperatures in the equatorial Pacific region. El Nino causes litter production in the Amazon forest to increase gradually [24]. The extreme increase in temperature and the accumulation of litter on the forest floor as a source of fuel will trigger forest fires [25].

In 2010 the KBDI value decreased and there were no extreme characteristics due to the high rainfall data. This is supported by research by [26] which states that there was a La Nina event in Indonesia in
2010. The La Nina phenomenon is a climate change where sea surface temperatures have decreased in the Pacific Ocean. This event resulted in the rainy season in Indonesia having a higher average rainfall than previous years.

3.2. Slope and slope direction
Slope is the degree of slope of the ground surface. The existence of an uneven topography provides a large frictional force on the movement of the wind causing the flames to spread easily. The Maros Regency area has slope conditions classified in Table 5.

| Number | Slope Classification | Area (Ha) | Percentage (%) |
|--------|----------------------|-----------|----------------|
| 1      | < 5%                 | 71,516.52 | 44.58          |
| 2      | 5-10%                | 3,342.65  | 2.08           |
| 3      | 10-25%               | 32,416.23 | 20.21          |
| 4      | 25-35%               | 20,783.35 | 12.96          |
| 5      | > 35%                | 32,363.77 | 20.17          |
|        | Total                | 160,422.52| 100            |

The direction of slope determined into four namely: North, East, South, and West as shown in Table 6.

| Number | Slope Direction | Area (Ha) | Percentage (%) |
|--------|-----------------|-----------|----------------|
| 1      | East            | 38,480.47 | 23.99          |
| 2      | North           | 39,728.44 | 24.76          |
| 3      | South           | 42,900.99 | 26.74          |
| 4      | West            | 39,312.63 | 24.51          |
|        | Total           | 160,422.52| 100            |

3.3. Types of Closure Land
The main component of the hazard of forest and land fires is the type of land cover. This is due to the availability of fuel whose flammability level comes from land cover. Several types of land cover in Maros Regency are bodies of water, primary dry land forest, secondary dry land forest, secondary mangrove forest, mixed dry land agriculture, dry land agriculture, rice fields, shrubs, swamp scrub, mines, ponds, airports, and settlement.

Several studies have reported that different types of land cover are closely related to forest fire rates [27,28]. Nunes et al. (2005) also reported that fires are selective for land cover types, so certain types have the potential to spread fires, such as shrubs, forest cover and agricultural land [29]. In line with the research of [30] reported that forest fires in Pu Mat National Park, Vietnam are highly correlated with land cover types, for example plantations and residential areas.

3.4. Accessibility of settlements and roads
Accessibility of settlements is a measure of the ease of access with a distance that is easily accessible by humans from the length of a path/settlement object. The basis for dividing distance classes from settlements is adopted from research conducted by [10] which states that the furthest distance that can be achieved by humans is ± 4 km. Residential distance has a difference of 1 km from 4 distance classes. The results of the area of settlement accessibility are in Table 7.
Table 7. Classification of the Area of Buffer Settlement Accessibility in District Maros.

| Number | Distance of Settlement | Area (Ha)   | Percentage (%) |
|--------|------------------------|-------------|----------------|
| 1      | < 1 Km                 | 57,717.25   | 35.98          |
| 2      | 1 - 2 Km               | 33,839.35   | 21.09          |
| 3      | 2 - 3 Km               | 22,952.20   | 14.31          |
| 4      | > 3 Km                 | 45,913.73   | 28.62          |
|        | Total                  | 160,422.52  | 100            |

Accessibility of roads District Maros is divided into five classifications. The results of road accessibility can be seen in Table 8.

Table 8. Classification of Areas Buffer Road Accessibility in District Maros.

| Number | Distance of Road | Area (Ha)   | Percentage (%) |
|--------|------------------|-------------|----------------|
| 1      | < 100 m          | 17,762.85   | 11.07          |
| 2      | 100-200 m        | 15,432.09   | 9.62           |
| 3      | 200-300 m        | 3,201.87    | 8.23           |
| 4      | 300-400 m        | 11,246.18   | 7.01           |
| 5      | > 400 m          | 102,779.54  | 64.07          |
|        | Total            | 160,422.52  | 100            |

Research by Susilawati and Syam’ani in 2021 [31] reported a very strong spatial correlation of the frequency of forest and land fires with the distance of human activities. In the Riam Kanan sub-watershed area, it shows that the frequency of fires increases as the distance from the main road increases as the number of hotspots increases and is almost close to 0.

3.5. Fire prone area

Fire Area prone areas are in the form of a map in the form of an area that presents the location of forest and land areas in the Maros Regency is prone to fires. The map is presented in the level of vulnerability composed of two information, namely the triggering factors of fire and drought factors. The results of the overlay (combined) of five hazard classes in Figure 13. The results of mapping areas prone to forest fires have a land area of Maros Regency is 1,604.22 Km².

Based on the determination of the class in the mapping of the potential for fire susceptibility, the percentage of the area of the fire susceptibility level is shown in Table 9. The potential for forest and land fire hazard based on the sub-district level in Figure 3 which is the result of the translation from Table 9 as follows.

Table 9. Percentage level of vulnerability in Maros Regency.

| Number | Vulnerability Level | Class | Area (Ha) | Percentage (%) |
|--------|---------------------|-------|-----------|----------------|
| 1      | Very Low            | 24 – 45 | 4,509.51  | 2.81           |
| 2      | Low                 | 46 – 66 | 20,169.59 | 12.57          |
| 3      | Medium              | 67 – 87 | 73,418.67 | 45.77          |
| 4      | High                | 88 – 108 | 58,188.08 | 36.27          |
| 5      | Very High           | 109 – 129 | 4,136.67  | 2.58           |
|        | Total               |       | 160,422.52 | 100            |
Figure 3. Graph of Fire Prone Area per District in District Maros.

Fires data in forest and land areas show that the large influence of fires is caused by community activities. The data has access distance between settlements with fire location data is < 500 m. This indicates a major influence on the accessibility of settlements and roads. Another influence is caused by the slope and direction of the slope so as to obtain the results as shown in Figure 3. According to [31], areas with uneven topography provide a large frictional force on wind movement. This frictional force causes the wind to decrease in speed. Areas that have high topography must have high frictional forces causing flames to spread easily when compared to low topography. Werth (2011) [32] and Viedma at al. (2015) [33] also reported that the spread of fire on the upper slopes was generally faster and more intense because it was supported by wind speed and the availability of fuel sources such as tree crowns that experienced pre-heating thus encouraging spread of fire.

The results of the spatial analysis in Figure 3 are the area of the mapping carried out to obtain a moderate level of fire susceptibility, which is 45.77%. High and very high levels of vulnerability are in the Districts of Tompobulu and Cenrana. This is due to the accessibility of settlements and close roads, the direction of the slopes getting enough sunlight which accelerates drying, and the slope of the slopes which facilitates the spread of fire. The level of vulnerability is very low in the Districts of Bontoa, Mallawa, and Marusu because the overall land cover is ponds that do not allow the emergence of hotspots. The following figure 4 presents an overview of areas with a level of vulnerability ranging from very low to high in Maros Regency.
4. Conclusions
The conclusions that can be drawn from the overall results of research conducted in Maros Regency are:
1. The dryness level of the KDBI based on rainfall and maximum air temperature has an average pattern every year with a fire prone level that is extreme in the August to October;
2. Mapping of fire susceptibility in Maros Regency to forest fire susceptibility by considering the factors of vegetation type, slope, slope direction, distance from the road, and distance from settlements, obtained information that the level of fire susceptibility in Maros Regency is dominated by medium class, namely 45.77% with an area of 734.19 km².

Suggestions
This research can be used as a benchmark or guide for alertness in paying attention to the level or potential of forest and land fire hazards with hazard characteristics that have been classified based on time and location in Maros Regency. And this research should be developed by including more variables that can trigger forest and land fires to occur.

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