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A comparative study of drought factors in the Mcarthur Forest Fire Danger Index in Indonesian Forest

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ABSTRACT

The calculation method used in Australia in assessing the forest fire hazard index is the McArthur Forest Fire Danger Index (MFFDI). One important component in the MFFDI calculation is the drought factor. The original MFFDI calculation method formulates the drought factor using parameters of temperature, relative humidity, and wind speed, or is given a constant value of 10 with certain conditions. The use of this parameter is not effective because the calculation of drought factors and index calculation, in general, is used at one time. The development of a suitable forest fire hazard index specifically implemented for forests in Indonesia is urgently needed. The character of forests in Indonesia is relatively different due to the influence of weather and climate that requires adjustments in its application. In the present work, a comparative study will be conducted by comparing the original drought factor of MFFDI, the drought factor of the Keetch-Byram Drought Index (KBDI), and the drought factor of the Mount's Soil Dryness Index (MDSI). The output generated from this study is the McArthur calculation method using drought factor's KBDI is the most suitable method to be used to calculate the forest fire hazard index in Indonesia.

Key words : *Drought Factor, Drought Index, McArthur, Forest Fire, Forest Fire Danger Index*

Introduction

The Australian Forest Fire weather technical report reports that MFFDI is relatively more sensitive to climate change compared to the Canadian Fire Weather Index (Dowdy *et al.*, 2009). Our previous research also concluded that the McArthur Forest Fire Danger Index is the most potentially used method of calculating the fire hazard index in Indonesia. Some types of forests and grasslands in Australia and Indonesia are similar. The fundamental difference between the occurrence of forest fires in the two countries is the contributing factor. In Indonesia, the cause of forest fires is dominated by the element of human intent to open large-scale agricultural and agricultural land (Kim *et al.*, 2016). While in Australia forest fires are caused by natural factors, accidental or human negligence. But both of these causes are based on the high drought factor so that even with the slightest cause of fire the forest becomes flammable.

One important component in MFFDI calculations is the use of drought factor variables. The drought factor is a value that represents the level of drought on the forest floor (Di Giuseppe *et al.*, 2016). The impact of the high drought will result in greater fire potential. Bulletin of the American Meteorological Society reported on drought-based predictions that resulted in forest fires in the East Kalimantan region (Herring *et al.*, 2015). The results of his research show a very close relationship between drought and forest fires.

This research is important to do in Indonesia because the relationship between drought and forest fires varies in each region (Varol *et al.,* 2017) depending on the character of the forest and its causes. Indonesia as a country is prone to forest fires requires prediction and modeling of forest fires on which to base mitigation. Refer to seriously controlled and controlled forest fires in Australia (Rahman *et al.*, 2018).

Referring to the MFFDI calculation method which has proven effective in Australia, it is necessary to consider the drought factor which is the main component in predicting forest fires. There are 4 choices for using drought in using the MFFDI method, namely using the original formula developed by McArthur, giving a constant value of 10 for certain conditions, using a drought factor in the Keetch-Byram Drought Index, or drought factor in the Mount's Soil Dryness Index. This research is needed to measure one of the most effective drought factor models in MFFDI. But the choice of using constant 10 on the drought factor is ignored because it is used only for certain conditions.

MFFDI classifies forest fire hazard index in 5 categories, namely extreme for index values greater than 50, very high for index values between 24 to 50, high for index values between 12 to 24, moderate for index values between 5 to 12, and low for index value less than 5 (Dowdy *et al.*, 2009). The challenge in designing this assessment of potential forest fire hazards is to simplify the size but not reduce the information on which the mitigation is based (Yeo, Kepert and Hicks, 2015).

Methodology

Relative Operating Characteristic (ROC)

ROC analysis was chosen because it has advantages in choosing the optimal index that does not depend on the class of data distribution (Pérez-sánchez *et al.*, 2017). The accuracy of each index is classified into four values: TP as true positive, FP as false positive, TN as true negative, and FN as false negative (Karouni *et al.,* 2013). TP is defined as a condition that predicted forest fires and true forest fires, FP is defined as predicted to burn but does not occur fire, TN is defined as predicted not to burn but fire occurs, and FN is defined by predicted not to burn and true to no fire. Based on these four conditions it can be concluded in two values, namely TPR as True Positive Rate and FPR as False Positive Rate which is shown in Equations 1 and 2.

$$TPR = TP/(TP+FN) \quad .. (1)$$

$$FPR = FP/(FP/TN) \quad .. (2)$$

where, TPR is defined as the correct value of predicted forest fires and true forest fires and FPR is defined as the value of prediction errors and no fires.

In addition to the two assessments, the ROC also makes it possible to look for values of accuracy and precision as written in Equations 3 and 4. Accuracy (ACC) is defined as the value of two conditions that indicate the occurrence of fire compared to all existing conditions, and precision is the ideal condition the predicted value and reality is proportional to the correct predictive value.

$$ACC = (TP+FN)/(TP+FP+TN+FN) \quad .. (3)$$

$$Precision = TP/(TP+FP) \quad .. (4)$$

Drought Factors (DF)

Original Drought Factor by MFFDI

The drought factor in the MFFDI calculation method has 2 models, namely using a calculation model based on meteorological parameters such as wind speed, temperature, relative humidity, and rainfall or given a constant 10 (Stephenson *et al.*, 2015). The approach to calculating the fire hazard index according to McArthur, which is defined in the McArthur Mark 5 Forest Fire Danger Meter, is written in Equation 5 (Sun, Trinder and Rizos, 2016)

$$FFDI = 2\exp(-0.45+0.987 \ln DF + 0.0338T - 0.0345H + 0.0234U), \quad .. (5)$$

where DF=Drought Factor, T=Temperature, H=Humidity, U=Wind Speed.

The drought factor in MFFDI was calculated using Equation 6 using the time parameters since the last rain and recorded daily precipitation (Khastagir, 2018).

$$DF = \frac{0.191(i+104)\ (N+1)1.5}{3.52(N+1)1.5 + P-1} \quad \text{if } DF > 10, DF = 10. \quad .. (6)$$

Drought Factor by KBDI

Keetch-Byram Drought Index (KBDI) is one of the drought index calculation models that is widely used to predict the danger of forest fires (Kumar and Dharssi, 2017). Drought is a potential disaster that is different from other disasters. The effect of drought produces forest fuel which increases slowly over a long period of time which then becomes a potential for ignition (Wilhite, 2000). The higher the drought index, the greater the potential for the fire to appear despite the small cause of the fire.

In the KBDI method, today's drought index calculation is obtained from yesterday's drought index coupled with today's drought factor. This research does not generally discuss the drought index, but rather focuses on the formulation of the drought factor. The drought factor (dQ) was reformulated by Crane (1982) on the International System unit scale written in equation 2 (Alexander, 1990).

$$DQ = \frac{[203.2 - Q]\,[0.968 \exp(0.0875T + 1.5552) - 8.30]d\tau}{1 + 10.88 \exp(-0.001736R)} \quad .. (7)$$

Where Q = moisture deficiency (mm), T = daily maximum temperature (°C), R = mean annual precipitation (mm), and dτ = time increament (=1 day).

Drought Factor by MSDI

Mount's Soil Dryness Index (MSDI) is an alternative drought index calculation method that can be used in addition to KBDI to calculate the drought potential of mountainous areas (Vinodkumar *et al.*, 2017). Although considered less accurate in detecting topsoil moisture, this method can be used to measure the dryness index in areas that are partly open and partly closed.

MSDI is commonly used effectively to balance empirically proven water infiltration (Vinodkumar *et al.*, 2017). One weakness of this calculation model is the drought factor is calculated by measuring the amount of water content in the soil layer. While the mountainous terrain that has the character of primary forest most of the forest floor cannot be penetrated by sunlight. This affects the amount of water in the soil because it is not absorbed by the heat.

Results

The data used as sample testing for this calculation uses meteorological data for 2 years (2014-2015) in monthly. Meteorological parameters used are maximum temperature, wind speed, relative humidity, the last day of rain, and rainfall. The calculation method used is McArthur FFDI by comparing 3 drought factors that can be used, namely the original drought factor MFFDI, KBDI drought factor, and MSDI drought factor. Table 1 shows the test results.

Using the same meteorological data yields different estimates of drought indices. Table 1 shows the results of the calculation of the index categorized by MFFDI using 3 choices of drought factors, namely the original drought factor from McArthur, the KBDI drought factor, and the MSDI drought factor. Each drought factor calculation model shows a different character. In general, the original drought factor shows that the index value is relatively higher than using the other two methods of drought factor. While the drought factor using MSDI is the lowest index rating.

Based on Table 1, then evaluated using ROC. In this study, the assumption of very high and extreme conditions is the easiest condition of forest fires. With these two conditions, then the fact that a forest fire actually occurred, concluded that there was a match between the predicted results of the calculation and the reality. While for high, moderate, and low conditions are safe conditions for fire hazards.

The results of the analysis using ROC are presented in Table 2, with the TP conditions obtained from a very high or extreme drought index and the fact that there is a fire, FP is a very high or extreme drought index condition and the fact that there is no fire, TN is a high, moderate, or drought index condition low and the fact that there is a forest fire, while FN is a drought index condition of high, moderate, or low and the fact that there is no forest fire.

Table 2 in the TPR column shows that the original drought factor using the default MFFDI formulation has the highest value because it predicts more fires while forest fires only occur in 3 of the 24 months studied. While the FPR column shows that the original formula has a value of 1 because it has the corresponding FP and TN values.

Prediction accuracy shows that MSDI gets the highest accuracy value, while the original formula has the lowest accuracy value. For precision values, the drought factor using KBDI is the biggest value compared to the other two drought factors.

Discussion

Referring to Table 1 shows that the drought factor using the original formula has a higher level of drought index because the drought factor resulting

Table 1. Results of Manual Calculation

Month	Original	KBDI	MSDI	Fact of Forest Fire
1	Very high	High	Moderate	No
2	Very high	High	Moderate	No
3	Very high	High	Moderate	No
4	Very high	High	Moderate	No
5	Very high	High	High	No
6	Extreme	Very high	Moderate	No
7	Extreme	Very high	High	No
8	Extreme	Very high	High	No
9	Extreme	Very high	High	Yes
10	Extreme	Very high	High	Yes
11	Very high	Very high	Moderate	No
12	Very high	Very high	Moderate	No
13	Very high	Very high	Moderate	No
14	Very high	Very high	Low	No
15	Very high	Very high	Low	No
16	Very high	High	Low	No
17	Very high	High	Low	No
18	Extreme	High	Moderate	No
19	Extreme	High	Moderate	No
20	Extreme	High	Moderate	No
21	Extreme	High	High	No
22	Extreme	High	High	No
23	Extreme	High	High	No
24	Extreme	High	High	Yes

Table 2. ROC Values, TPR, FPR, Accuracy, and Precision

	TP	FP	TN	FN	TPR	FPR	Accuracy	Precision
Original	3	21	0	0	1.000	1.000	0.125	0.143
KBDI	2	8	1	13	0.133	0.889	0.625	0.250
MSDI	0	0	3	24	0.000	0.000	0.875	0.000

from the calculation ranges from 4 to 10 and a small portion of the above 10. The drought factor using KBDI is more conservative with values ranging from -1 up to 1. While MSDI is lower because the majority of drought factors are below 0, this occurs because the mountainous drought conditions are slower to dry compared to the flat area.

Referring to the results of the ROC analysis in table 2, it shows that the accuracy using the MSDI drought factor is highest because of the predicted 24 months, all of them predict no forest fires. The fact is 21 months there was no fire and only 3 months that there was a fire. But even though it has a high accuracy value, the drought factor of the MSDI model is not good for a forest fire early warning system because of the 3 times the MSDI fires have never been predicted before.

The results of the prediction of forest fires using the drought factor using the original formula show good predictions, because of the three times the forest fires have been predicted beforehand. However, it can be seen that from 24 months predicted all forest fires are predicted to occur. It can be concluded that despite having an accurate level of predicting good forest fires, they occur because they are all predicted to burn. This situation is also not good for use as an early warning system for forest fires.

The conclusion of this study is that MFFDI uses KBDI's drought factor as the most promising formulation option to be used in the early warning system of forest fires because of 3 times the forest fires have been successfully predicted 2 times before. While from 21 months there was no fire successfully predicted as many as 13 months earlier is true.

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