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KBDI Analysis of Peatland Drought Index Modification in Liang Anggang Protected Forest Area Block 1

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ABSTRACT

Peatlands are a unique and fragile ecosystem, as they are located in a swampy environment. Peatlands play an important role in maintaining biodiversity and climate regulation. Peat soils have high organic levels; when the water in peat soils is reduced, the fibers on peat soils are prone to fire. This study aims to analyze the magnitude of the drought index and map the temporal drought index in the Liang Anggang Protected Forest area. The analysis methods carried out include data collection, namely rainfall data from 2012 to 2021 and maximum daily temperature data, which is then processed using several stages of analysis from the Keech Byram Drought Index (KBDI) model modification in peatland condition. It was concluded that the region has an average high drought index that occurs from July to August, and the greater the value of the drought index, the more directly proportional to the number of fires but inversely proportional to rainfall. Based on the temporal analysis, several conclusions were obtained through various conditions. Drought index levels increased significantly started from May, and the peak of drought in September and beginning to decrease the following month.

Keywords: KBDI modification, Temporal Drought Index, Hotpots, Liang Anggang Protected Forest

1. INTRODUCTION

Peatland is an ecosystem in nature that is unique but also very fragile because it is located in a swampy environment (Novitasari *et al.*, 2018). The function of peatlands also plays an important role in daily life, such as maintaining the water availability and water need. Peatlands are very widespread in Indonesia, which makes Indonesia ranked 4th as the country with the largest peatland in the world after Canada, Russia, and America, covering an area of 20 million hectares (Novitasari *et al.*, 2018). Burning forests is one of the causes of the destruction of forests in the world and is very detrimental not only in terms of the completeness of forests but also results in very large losses for the economic, social, and ecological sectors of forest areas (Novitasari *et al.*, 2018). Fires that occur in wetlands are more difficult to detect and spread quickly, requiring better handling (Adinugroho *et al.*, 2004). Peatlands displaced by fires caused the land to be unplanted and have uneven land surfaces. Liang Anggang Protection Forest is located between Banjarbaru City and Banjar Regency, South Kalimantan. Most of the land in the Liang Anggang Protection Forest is included in peatlands that require more handling because peatlands will be prone to fire if the groundwater level is below average. If peat soil has a deep groundwater level, it will be easy to experience fires due to dry peat soil. Land drought index analysis is one way and solution to anticipate and reduce the risk of peatlands becoming flammable. This study aims to analyze the magnitude of the drought index and map the temporal drought index in the Liang Anggang Protected Forest area.

2. LITERATURE REVIEW

Hydrology

Water is an element that is on earth and is very important as a support for the life of creatures in it, such as humans, plants, and animals. This process of water circulation on earth is referred to as the hydrological cycle (Sri Harto, 2009). Science is related to water on earth, both regarding its occurrence, its eels, its distribution and circulation on earth, and the relationship with living things and their environment (Bambang Triadmodjo, 2008). The hydrological cycle starts from the evaporation of water, which then undergoes condensation into clouds. The clouds that form then fall to the earth in the form of water or snow and repeat themselves (Novitasari Novitasari, 2010).

Peat Formation

Peat formation is an event that requires a fairly long process because peat is formed from the process of weathering the remains of moss, grasses, trees, and other biological remains, as well as decay from stars and other animal substances (Mawardi, Maftu'ah and Anwar, 2013). A wet environment is a place where peat soils are formed. The age of the peat is from how deep the peat soil is; the older it means, the older the peat (ICRAF, 2000).

Peat Characteristics

Peat can be distinguished from different points of view as it is classified according to the degree of maturity, fertility, position of formation, and depth (van den Eelaart, 2005). One of them is the classification according to maturity, which is divided into 3, namely fibric peat (raw), hemic peat (half-ripe), and sapric peat (mature) (Najiyati *et al.*, 2005).

Keech-Byram Drought Index

The Keech-Byram Drought Index (KBDI) modification for the peatland method (Novitasari *et al.*, 2019)requires 3 (three) main modifiers to calculate the drought index value that can determine the degree of danger from drought due to drought, as follows.

a. Average annual rainfall from local/local weather stations
b. Daily rainfall
c. Maximum temperature

The way of calculation of this method is based on the following equation.

$$KBDI_{p,t} = KBDI_{p,t-1} + DF_{p,t}\text{-}RF_{p,t}$$

With:

$KBDI_{p,t}$: drought index today
$KBDI_{p,t-1}$: previous day's drought index
$DF_{p,t}$: drought factors
$RF_{p,t}$: effective rain

The effective precipitation value (RFt) is determined using the following equation.

$$RFt = \begin{cases} (R_t - 5{,}1), R_t \geq 5{,}1\ mm/day, first\ rainy\ day \\ R_t, R_{t-1} \geq 5{,}1\ mm/day, second\ day\ and\ next\ rainy\ day \\ 0, R_t < 5{,}1\ mm/day \end{cases}$$

Where R_t is the daily rainfall at t and Rt-1 is the daily rainfall at t-1. And to determine the drought factor by the following equation.

$$DF_t = (wc\text{-}KBDIt\text{-}1)\ \frac{(ae^{(bTm+1{,}5552)} - c)10^{-3}}{1+10{,}88e^{(-0{,}001736R_0)}}$$

With:

DF_t : drought factors (mm)

w_c	: airy capacity of water available in layers (mm)
$KBDI_{t-1}$	: moisture deficiency (KBDI at t-1)
T_m	: daily maximum air temperature (°C)
t	: time increase (day)
R_0	: average annual rainfall (mm)
a dan *c*	: coefficients affected by the average annual rainfall (R_0)
b	: coefficient affected by evapotranspiration

Table 1. Climate Variables and Drought Factor Coefficients for Tropical Wetland and Tropical Peatlands due to El Niño

Parameters	Tropical Wetlands	Tropical Peatlands due to El Niño
T_m [°C]	32	32
R_0 [mm]	2540	1650
a	0,4982	0,6225
b	0,0905	0,0905
c	4,27	5,34
w_c	203	400

Source: (Novitasari *et al.*, 2019)

Drought index classes are classified into four tiers, as presented in Table 2.

Table 2. KBDI Drought Index Class Modified for Wetland and Tropical Peatland Conditions due to El Niño

Class	KBDI Index	KBDI Index on Tropical Peatlands
Low	0-100	0-200
Medium	101-150	201-300
High	151-175	301-350
Extreme	>175	>350

Source: (Novitasari *et al.*, 2019)

3. RESEARCH METHODS

Steps of work on this research:

1) Preparation and study of related literature.
2) Collection of necessary data such as daily rainfall data for 2012-2021, the maximum daily temperature in 2012-2021, physical properties of peat soils in Liang Anggang Block 1 Protected Forest, and the number of fires in 2012-2021.
3) Calculating effective daily rainfall (RF_t) by using daily rainfall data.
4) Calculating drought factors (DF_t) for tropical wetland conditions and tropical peat conditions due to el niño using maximum daily temperature data, the previous day's drought index ($KBDI_{t-1}$), climate variables, and drought factor coefficients.
5) Calculate today's drought index ($KBDI_t$) by using the previous day's drought index data ($KBDI_{t-1}$), drought factors (DF_t), and effective daily rainfall (RF_t).
6) Determine the drought index level with the KBDI drought index class table.
7) Mapping the temporal drought index in the Liang Anggang Block 1 Protected Forest area.

4. RESULTS AND ANALYSIS

Results of Rainfall and Fire Data Analysis

Daily rainfall data every year from 2012 to 2021 is shown in Table 3.

Table 3. Monthly Cumulative Value of Daily Rainfall from 2012 to 2021

Monthly Cumulative Value of Daily Rainfall from 2012 to 2021									
Month	Years								
	2012	2014	2015	2016	2017	2018	2019	2020	2021
January	220.6	279.1	338.7	383.2	384.8	279.8	293.2	457.8	898.3
February	155.7	299.7	502.7	350.1	264.3	473.8	326.2	532	417.6
March	263.6	295.2	79.8	329.1	172.5	552.5	328.4	264.5	166
April	402.8	213.9	274.3	333.1	236.6	212.1	308.5	59.2	213.6
May	126.3	211.3	157.8	292.3	266.1	44.4	84.2	175	199.6
June	162.3	194.2	107.2	212.8	208.9	152.4	171.5	126.8	222.3
July	144.5	75.3	44.8	129.3	138.7	56.3	9.4	79.2	63.8
August	27.1	19.7	45	80.5	98.5	64	26.7	115.1	161.8
September	32.3	15	0	155.2	116.4	16	2.6	109.7	121.7
October	165.8	0	29.2	200.6	102.5	113.2	57.7	173.2	144.8
November	337.5	52.1	83.5	448.7	377.2	217.9	91	351.7	283.9
December	463.2	300.1	474.4	328.4	390.8	608.5	325	500.9	327.6
Number Per Year	2501.7	1955.6	2137.4	3243.3	2757.3	2790.9	2024.4	2945.1	3221

Source: Secondary Data, Processed (2022))

Data on the number of fires combined with the history of fire warnings in Banjar Regency and Banjarbaru City every year from 2012 to 2021 is shown in Table 4.

Table 4. Cumulative Fire Points of Banjar Regency and Banjarbaru City

Cumulative Hotspots										
Month	Years									Total
	2012	2014	2015	2016	2017	2018	2019	2020	2021	
January	1	0	0	13	1	1	0	1	0	17
February	0	1	0	1	1	4	2	0	0	9
March	1	2	0	1	5	1	2	1	1	14
April	4	2	1	0	2	6	0	0	5	20
May	14	8	5	0	4	8	5	0	11	55
June	8	4	16	4	11	17	6	5	11	82
July	50	40	47	7	16	74	25	2	27	288
August	40	57	57	33	53	49	98	54	13	454
September	59	92	195	34	23	83	133	8	32	659
October	56	47	77	21	50	76	29	27	14	397
November	21	15	23	3	3	19	24	6	2	116
December	4	0	7	0	1	1	6	0	0	19
Number Per Year	258	268	428	117	170	339	330	104	116	

Source: Secondary Data, Processed (2022))

The relationship between the number of fires and rainfall from 2012 to 2021 is shown in Figure 1 below.

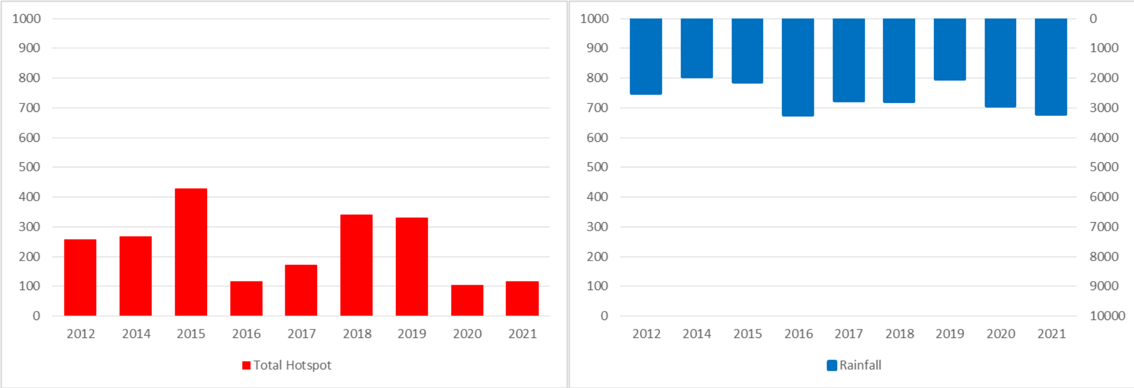

Figure 1. Graph of Total Rainfall and Annual Hotspots

From Figure 1, it can be concluded that 2015 was the year when land fires occurred the most, with rainfall that was below the average of 2500 mm/year. 2014 and 2019, which had low annual rainfall, also had a high number of annual hotspots.

Drought Index Calculation Results Tropical Wetland Conditions

The calculation results for a full one month for tropical wetland conditions can be seen in Table 5 below.

Table 5. Calculation Results for Tropical Wetland Conditions

Date	Rain 24 Hours (Rt)	Effective Rain (RFt)	Maximum Daily Temperature(Tm)	Previous Day's Index Reduced by Effective Rain (KBDIt-1)	Drought Factors (DFt)	Drought Index (DI)	Index Level
1	2	3	4	5	6	7	8
01-01-2012	0	0	31.8	0	6.754	6.754	Low
02-01-2012	18.2	13.1	31.2	0	6.357	6.357	Low
03-01-2012	0	0	28.6	6.357	4.711	11.068	Low
04-01-2012	4.7	0	32.4	11.068	6.783	17.851	Low
05-01-2012	4.8	4.4	29.8	13.451	5.144	18.595	Low
06-01-2012	0	0	31.2	18.595	5.774	24.369	Low
07-01-2012	10.5	5.4	32.3	18.969	6.439	25.408	Low
08-01-2012	18.5	13.4	30.4	12.008	5.513	17.521	Low
09-01-2012	28.1	23	30.4	0	5.859	5.859	Low
10-01-2012	0	0	30.6	5.859	5.808	11.667	Low
11-01-2012	0	0	31.2	11.667	5.991	17.658	Low
12-01-2012	13.6	8.5	29.8	9.158	5.261	14.419	Low
13-01-2012	0.2	0	30.2	14.419	5.333	19.752	Low
14-01-2012	2.8	0	31.4	19.752	5.856	25.608	Low
15-01-2012	0	0	29.4	25.608	4.619	30.227	Low
16-01-2012	15.4	10.3	32.2	19.927	6.341	26.268	Low
17-01-2012	5.4	0.3	28.5	25.968	4.197	30.165	Low
18-01-2012	0	0	32.4	30.165	6.108	36.273	Low
19-01-2012	6	0.9	31	35.373	5.144	40.516	Low
20-01-2012	0.7	0	31.1	40.516	5.037	45.553	Low
21-01-2012	9.8	4.7	30	40.853	4.492	45.345	Low
22-01-2012	0	0	32.4	45.345	5.571	50.916	Low
23-01-2012	0	0	31.8	50.916	5.060	55.977	Low
24-01-2012	0	0	32	55.977	4.991	60.968	Low
25-01-2012	2.8	0	34.2	60.968	6.002	66.970	Low
26-01-2012	0	0	32.2	66.970	4.712	71.682	Low
27-01-2012	8.5	3.4	29.7	68.282	3.619	71.900	Low
28-01-2012	12.5	7.4	32	64.500	4.702	69.202	Low
29-01-2012	14.5	9.4	32.4	59.802	5.060	64.862	Low
30-01-2012	24.1	19	27.2	45.862	3.246	49.109	Low
31-01-2012	19.5	14.4	32	34.709	5.713	40.422	Low

Source: Secondary Data, Processed (2022)

An example of the calculation below is an explanation of the results of Table 5 above.

a. Effective Rain (RF_t)

Effective rain (RF_t) is the value of rain obtained from the rain factor formula.

$$RFt = \begin{cases} (R_t - 5{,}1), R_t \geq 5{,}1\ mm/day, first\ rainy\ day \\ R_t, R_{t-1} \geq 5{,}1\ mm/day, second\ day\ and\ next\ rainy\ day \\ 0, R_t < 5{,}1\ mm/day \end{cases}$$

- First Calculation
  Rain on 2012-01-02 of 18.2 mm
  Effective rain = 18,2 – 5,1
  = 13,1 mm
- Second Calculation
  Rain on 2012-01-04 of 4,7 mm
  Rain on 2012-01-05 of 4,8 mm
  Effective rain = 4,7 + 4,8 – 5,1
  = 4,4 mm (on date 05-01-2012)
- Third Calculation
  Rain on 2012-01-14 of 2,8 mm
  Effective rain = 2,8 – 5,1
  = -2,3 mm (then the effective rain value becomes 0)

b. $KBDI_{t-1}$ (Previous Day's Drought Index)

On 2012-01-01, the result of the previous day's drought index is assumed to be 0 because the previous day's drought index is not included in the calculation. An example of a calculation on 2012-01-08 is like this link.

$KBDI_{t-1\ (2012\text{-}01\text{-}08)} = KBDI_{p,t} - RF_{p,t}$
$= 25{,}408 - 13{,}400$
$= 12{,}008$

c. Drought Factors (DF_t)

Drought factors for fire conditions in wetlands are assumed to occur at groundwater level conditions of 203 mm. An example of calculating the frequency factor on 2012-01-08 is as follows.

$$DF_t = (w_c - KBDI_{t-1}) \frac{(ae^{(bTm+1{,}5552)} - c)10^{-3}}{1+10{,}88e^{-0{,}001736R0)}}$$

$$DF_t = (203 - 12{,}008) \frac{(0{,}4982e^{((0{,}0905*30{,}4)+1{,}5552)} - 4{,}27)10^{-3}}{1+10{,}88e^{-0{,}001736*2540)}}$$

$$DF_t = 5{,}513$$

d. $KBDI_{p.t}$ (Drought Index Today)

Today's drought index was obtained from the previous day's drought index (KBDIt-1) minus effective rain (RF_t) coupled with drought factors (DF_t). An example of today's drought index calculation on 2012-01-08 looks like the following.

$KBDI_{p.t} = KBDI_{t-1} + DF_t$
$KBDI_{p.t} = 12{,}008 + 5{,}513$
$KBDI_{p.t} = 17{,}521$

e. Drought Index Level

Determine the level of drought index by comparing the class of drought index KBDI in Table 2 with the value of today's drought index that has been obtained. For 2012-01-08, the drought index value has been obtained at 17.521 in the range of 0-100 values which belong to the low class.

Drought Index Calculation Results of Tropical Peat Conditions due to El Niño

The calculation results for a full month for tropical wetland conditions can be seen in Table 6 below.

Table 6. Calculation Results for Tropical Peat Conditions due to El Niño

Date	Rain 24 Hours (Rt)	Effective Rain (RFt)	Maximum Daily Temperature(Tm)	Previous Day's Index Reduced by Effective Rain (KBDIt-1)	Drought Factors (DFt)	Drought Index (DI)	Index Level
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
01-01-2012	0	0	31.8	0	11.620	11.620	Low
02-01-2012	18.2	13.1	31.2	0	10.936	10.936	Low
03-01-2012	0	0	28.6	10.936	8.138	19.074	Low
04-01-2012	4.7	0	32.4	19.074	11.753	30.827	Low
05-01-2012	4.8	4.4	29.8	26.427	8.851	35.278	Low
06-01-2012	0	0	31.2	35.278	9.971	45.249	Low
07-01-2012	10.5	5.4	32.3	39.849	11.001	50.851	Low
08-01-2012	18.5	13.4	30.4	37.451	9.136	46.587	Low
09-01-2012	28.1	23	30.4	23.587	9.486	33.072	Low
10-01-2012	0	0	30.6	33.072	9.438	42.510	Low
11-01-2012	0	0	31.2	42.510	9.774	52.284	Low
12-01-2012	13.6	8.5	29.8	43.784	8.440	52.224	Low
13-01-2012	0.2	0	30.2	52.224	8.586	60.810	Low
14-01-2012	2.8	0	31.4	60.810	9.463	70.273	Low
15-01-2012	0	0	29.4	70.273	7.496	77.769	Low
16-01-2012	15.4	10.3	32.2	67.469	10.056	77.525	Low
17-01-2012	5.4	0.3	28.5	77.225	6.681	83.906	Low
18-01-2012	0	0	32.4	83.906	9.753	93.659	Low
19-01-2012	6	0.9	31	92.759	8.231	100.990	Low
20-01-2012	0.7	0	31.1	100.990	8.092	109.082	Medium
21-01-2012	9.8	4.7	30	104.382	7.150	111.532	Medium
22-01-2012	0	0	32.4	111.532	8.900	120.433	Medium
23-01-2012	0	0	31.8	120.433	8.121	128.554	Medium
24-01-2012	0	0	32	128.554	8.046	136.599	Medium
25-01-2012	2.8	0	34.2	136.599	9.718	146.318	Medium
26-01-2012	0	0	32.2	146.318	7.672	153.989	High
27-01-2012	8.5	3.4	29.7	150.589	5.849	156.438	High
28-01-2012	12.5	7.4	32	149.038	7.438	156.477	High
29-01-2012	14.5	9.4	32.4	147.077	7.804	154.880	High
30-01-2012	24.1	19	27.2	135.880	4.763	140.644	Medium
31-01-2012	19.5	14.4	32	126.244	8.114	134.358	Medium

Source: Secondary Data, Processed (2022)

An example of the calculation below is an explanation of the results of Table 5 above.

a. Effective Rain (RF_t)

Effective rain (RF_t) is the value of rain obtained from the rain factor formula.

$$RFt = \begin{cases} (R_t - 5{,}1), R_t \geq 5{,}1\ mm/day, first\ rainy\ day \\ R_t, R_{t-1} \geq 5{,}1\ mm/day, second\ day\ and\ next\ rainy\ day \\ 0, R_t < 5{,}1\ mm/day \end{cases}$$

- First Calculation
  Rain on 2012-01-02 of 18.2 mm
  Effective rain = 18,2 – 5,1
  = 13,1 mm
- Second Calculation
  Rain on 2012-01-04 of 4,7 mm
  Rain on 2012-01-05 of 4,8 mm
  Effective rain = 4,7 + 4,8 – 5,1
  = 4,4 mm (on date 2012-01-05)

- Third Calculation
  Rain on 2012-01-14 of 2,8 mm

Effective rain = 2,8 – 5,1
= -2,3 mm (then the effective rain value becomes 0)

b. $KBDI_{t-1}$ (Previous Day's Drought Index)

On 2012-01-01, the result of the previous day's drought index is assumed to be 0 because the previous day's drought index is not included in the calculation. An example of a calculation on 2012-01-08 is like this link.

$$KBDI_{t-1\,(08\text{-}01\text{-}2012)} = KBDI_{p,t} - RF_{p,t}$$
$$= 50{,}851 - 13{,}400$$
$$= 37{,}451$$

c. Drought Factors (DF_t)

Drought factors for fire conditions in wetlands are assumed to occur at groundwater level conditions of 203 mm. An example of calculating the frequency factor on 2012-01-08 is as follows.

$$DF_t = (w_c - KBDI_{t-1})\,\frac{(ae^{(bTm+1{,}5552)}-c)10^{-3}}{1+10{,}88e^{-0{,}001736R0)}}$$
$$DF_t = (400 - 37{,}451)\,\frac{(0{,}6225e^{((0{,}0905*30{,}4)+1{,}5552)}-5{,}34)10^{-3}}{1+10{,}88e^{-0{,}001736*1650)}}$$
$$DF_t = 9{,}136$$

d. $KBDI_{p.t}$ (Drought Index Today)

Today's drought index was obtained from the previous day's drought index ($KBDI_{t-1}$) minus effective rain (RF_t) coupled with drought factors (DF_t). An example of today's drought index calculation on 2012-01-08 is as follows.

$$KBDI_{p.t} = KBDI_{t-1} + DF_t$$
$$KBDI_{p.t} = 37{,}451 + 9{,}136$$
$$KBDI_{p.t} = 46{,}587$$

e. Drought Index Level

Determine the level of drought index by comparing the class of drought index KBDI in Table 2 with the value of today's drought index that has been obtained. For the date 08-01-2012, the drought index value has been obtained at 46.587, which is in the range of 0-200 values which are included in the low class.

Relationship of Fire Points, Rainfall, and Drought Index

The data on the distribution of fires that have been analyzed and have been known to be the most known years of fires are then correlated with the drought index in the same year, where the correlation between the number of fire distributions and the drought index can be seen in the following figure.

Figure 2. Relationship of Hotspots, Rainfall to Drought Index

In Figure 2, it can be translated that fires are recorded a lot when drought levels are on an extreme scale. This shows at a time when the condition of the area is in a dry state (extreme drought index. On the scale of the low drought index, little was found in the presence of fires and even none at all. This shows that fires that indicate a fire have a tendency that is not fixed.

Temporal Drought Index Analysis Results

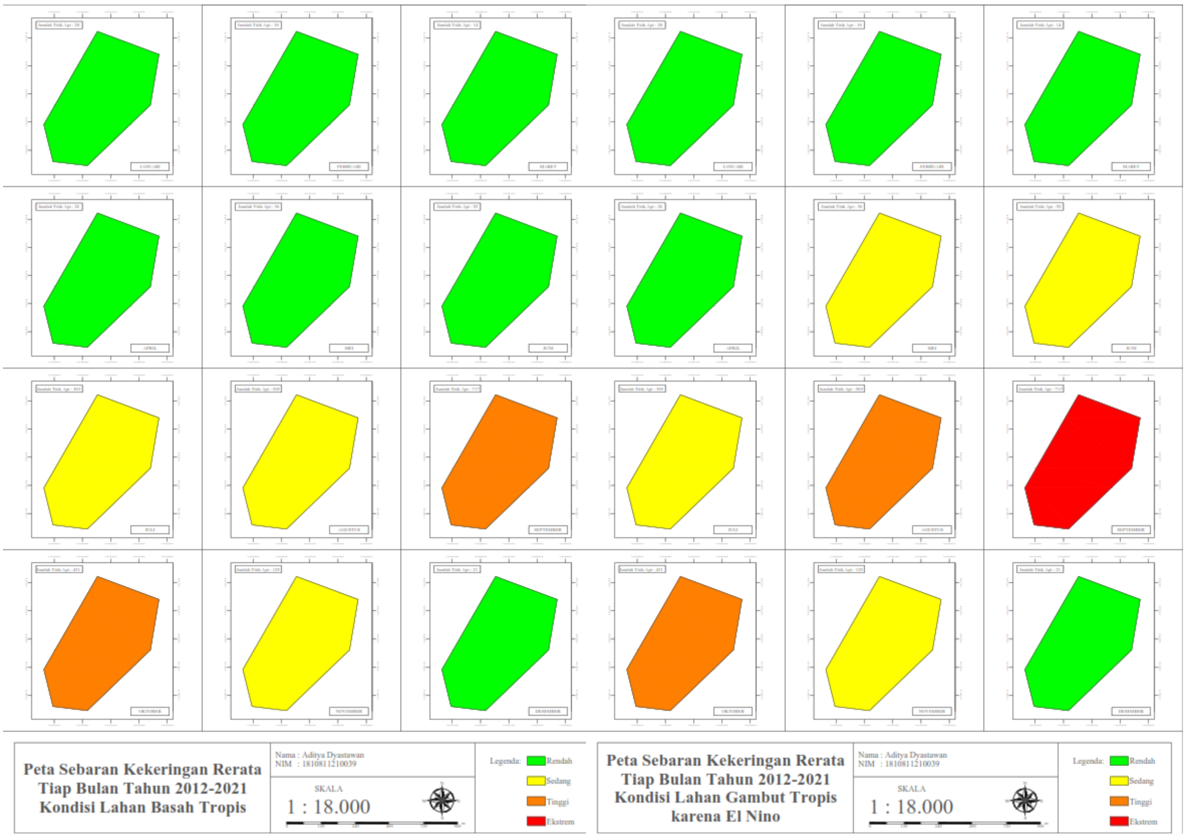

Figure 3. Temporal Drought Index of Protected Forests

Figure 3 of the results of spatial analysis of the water drought index for each month, shows that the Liang Anggang Block 1 Protected Forest area in tropical wetland conditions in January, February, March, April, May, and June did not experience drought. From July to August, there are already drought areas with a moderate scale. The peak of the drought occurs from September to October on a large scale. The month of November experienced a scale decline until December. In tropical peatland conditions due to El Niño, January, February, March, and April did not experience drought. From May to July, there have been areas of moderate drought. In August, the drought index further increased to a large scale. The peak of the drought occurred in September on an extreme scale. The month of October decreased in scale until December.

5. CONCLUSIONS AND SUGGESTIONS

Conclusion

From the results of the analysis and calculations that have been carried out, it can be concluded as follows.

1. Wetland modifications showed a high drought index in September with a value of 163,673, peatland modifications of El Niño conditions showed an extreme drought index in September with a value of 351,850, and KBDI modifications for the physical properties of fibric peat showed the extreme drought index was in September with a value of 372,542. Based on the data obtained, the greater the drought index value in a condition is directly proportional to the number of fires recorded but inversely proportional to the recorded rainfall data.
2. Temporal indices in tropical wetland conditions did not obtain extreme drought index levels, and the highest point was in September, with 659 hotspots. Tropical peat conditions due to El Niño obtained extreme drought index levels in September, and the highest point was in September with 659 hotspots. The condition of the physical properties of peat obtained the level of extreme drought index in August, September, and October, and the highest point was in September, with the number of fires as many as 1510 points.

Recommendation

From the results of the analysis and calculations, some recommendations that can be considered are as follows.

1. This study can be developed to calculate the drought index analysis using other methods, and then it can be compared with this study so that it can provide a better picture.
2. It is necessary to observe groundwater levels covering the dry season up to the rainy season in the study area, to obtain more accurate results from the relationship of groundwater level height with the drought index.
3. Forest and land fire vulnerability information can be used to predict the threat of fire hazards in an area, so such information should be used to minimize the occurrence of forest and land fire hazards in a fairly vulnerable month.

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