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Drought Analysis in Ketapang District using the Keetch-Byram Drought Index Method

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Abstract

Ketapang Regency is one of the areas in West Kalimantan that is prone to drought. Drought can trigger forest and land fires. In this research, the Keetch-Byram Drought Index (KBDI) method was used to determine the level of drought in Ketapang Regency. The KBDI method relies on annual rainfall accumulation, daily rainfall, and maximum air temperature. The KBDI values obtained were correlated with the number of hotspots using Pearson correlation. This research was conducted throughout 2018-2022. Based on the monthly average KBDI value, the highest drought in Ketapang Regency occurred in August and September, while the lowest drought occurred in December and January. In terms of the annual average, the highest drought occurred in 2019. During the ENSO phenomenon in 2019, the El Niño phase experienced higher drought than the La Niña phase and normal years. In the El Niño phase, drought levels reach high to extreme categories. The correlation value between annual KBDI and the number of hotspots is 0.88, indicating a solid relationship. An increase in the KBDI value will be followed by an increasing number of hotspots.

Keywords: Drought; ENSO; KBDI; Ketapang Regency.

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Introduction

Indonesia has a tropical climate with the potential for drought when entering the dry season. Based on Koppen's climate classification, Indonesia is an area with a tropical rainforest climate (Af) characterized by relatively uniform air temperatures (Hidayat & Farihah, 2020). An increase in air temperature in the dry season can potentially lead to drought (Malino et al., 2022). A long dry season can cause drought because the soil air reserves will run out due to evaporation, transpiration, or other uses (Darojati et al., 2015). Drought is a natural phenomenon that is a side effect of climate variability (Auliyani & Rekapermana, 2020). Drought is included in the hydrometeorological natural disasters that occur due to reduced rainfall intensity over a long period (Fatehah et al., 2022). Drought can cause crop failure and trigger forest fires. One phenomenon affecting drought is the El Niño Southern Oscillation (ENSO). The ENSO phenomenon is divided into three phases, namely the neutral, La Niña, and El Niño phases. The La Niña phase is more synonymous with the rainy season due to high rainfall intensity and causes flooding events (Ilhamsyah, 2012). The El Niño phenomenon causes a significant decrease in rainfall in Indonesia and can cause drought in Indonesia (Astuti M. P. et al., 2024). Along with the drought that occurs, it can cause hotspots.

Hotspot is a term used to refer to pixels with temperature values above a certain threshold based on the results of satellite image interpretation (Saharjo & Effendi, 2023). Hotspots do not necessarily describe a forest fire incident, but hotspots can be indicators used for early detection of forest fire events (Aflahah et al., 2018). The number of hotspots is a key determinant of the increase in forest fires and peat swamp forest fires (Cahyono et al., 2015). The more hotspots are distributed, the higher the potential for forest and land fires (Humam et al., 2020). Hotspots will increase in dry months or the dry season (Nahlunnisa & Sopiyandi, 2023).

Ketapang Regency is one of the regencies in West Kalimantan, with 20 sub-districts, and is the largest regency in West Kalimantan. Astronomically, Ketapang Regency is located at 0°19'26.51" South to 3°4'16.59" South and 109°47'36.55" East to 111°21'37.36" East. Forest areas and land areas still dominate the region in Ketapang Regency. Ketapang Regency has monsoon rainfall. The peak of the dry season occurs in June–July–August. During the dry season, Ketapang Regency is prone to drought, which can impact forest and land fires. In addition, most of the land in Ketapang Regency is peat, which has the potential to cause fires to spread quickly. Research by Dicelebica et al. (2022) shows that the area of peatland in Ketapang Regency has an area of 856,296.05 hectares Ketapang Regency is the region with the worst cases of forest fires in West Kalimantan.

One method that can be used to determine the value of the drought index is the Keetch-Byram Drought Index (KBDI) method. The KBDI method was first developed in 1968 to measure drought levels based on the climate of Florida, USA (Keetch & Byram, 1968). The KBDI method uses parameters of annual rainfall accumulation, maximum daily air temperature, and daily rainfall accumulation. The results of the study by Ningsih et al. (2022) showed that Ketapang Regency was the area with the highest drought index and occurred in August. Susanti et al. (2013) conducted a study on the level of drought in Pontianak City using the KBDI method. The study's results showed that during 2006-2008, the most extensive drought index in Pontianak City occurred in 2006, with an extreme KBDI level in August. 2006, the El Niño phenomenon occurred, so there was a long drought. The KBDI value and the number of hotspots show a robust correlation. Anastasia et al. (2021) conducted a study on the fire danger level in West Kalimantan using the Fire Weather Index (FWI) method. The study results showed that the FWI value had a very high correlation with the number of hotspots.

Research related to the level of drought in West Kalimantan using the Standardized Precipitation Index (SPI) method has been conducted by Qonita et al. (2019) from 1985 – 2016. Based on the research, the worst drought occurred in 2014 and 2015 in the Ketapang Regency area. Fatehah et al. (2022) conducted a study using the Standardized Precipitation-Evapotranspiration Index (SPEI) method to determine the variation of drought in West Kalimantan. The SPEI analysis showed a very dry drought severity level, which was identified in June 2004. Nahlunnisa & Sopiyandi (2023) have conducted a study on the distribution of hotspots as a predictor of forest and land fires. The study shows that Ketapang Regency has many hotspots, with 7542 in 2021-2022. The latest research on the drought index has been conducted by Tsabita (2023) using the KBDI method in West Kalimantan at 2001-2021. This study shows that Ketapang Regency is the area most prone to drought. In addition, the relationship between the drought index value and the number of hotspots shows a robust correlation.

Based on previous studies related to drought in West Kalimantan, a study related to drought was conducted that only focused on the Ketapang Regency area. The years used in the study are 2018 - 2022 which includes the ENSO phenomenon. The research was conducted using the Keetch-Byram Drought Index (KBDI) method with parameters of annual rainfall accumulation, daily rainfall accumulation, and maximum daily temperature. The calculated KBDI value will be analyzed spatially. The purpose of this study is to determine the magnitude of the drought level in Ketapang Regency and its relationship with hotspots. The study was also conducted during the El Niño phenomenon, which is identical to the decrease in rainfall intensity. This research is expected to provide information for drought mitigation and can be a reference for further research.

Materials and Methods

The data used in this study are secondary, which are daily rainfall accumulation data, annual rainfall accumulation data, and maximum daily air temperature data in the range of 2018 - 2022. In addition, this study uses hotspot data from the MODIS satellite. Rainfall and air temperature data were obtained through Copernicus ECMWF, which can be accessed via the page Climate Data Store. Hotspot data was obtained from the Ministry of Environment and Forestry, which can be accessed through the page SiPongi+ (Sistem Pemantauan Karhutla). The data from Copernicus ECMWF has a resolution of 27.75 km, while the hotspot data from the MODIS satellite has a resolution of 1 km.

The research location is in Ketapang Regency, and the data collection is 50 points with a grid of 0.25° × 0.25°. The research location used is located at 109.8° E to 111.3° E and 0.3° S to 3.1° S. The research location is shown in Figure 1.

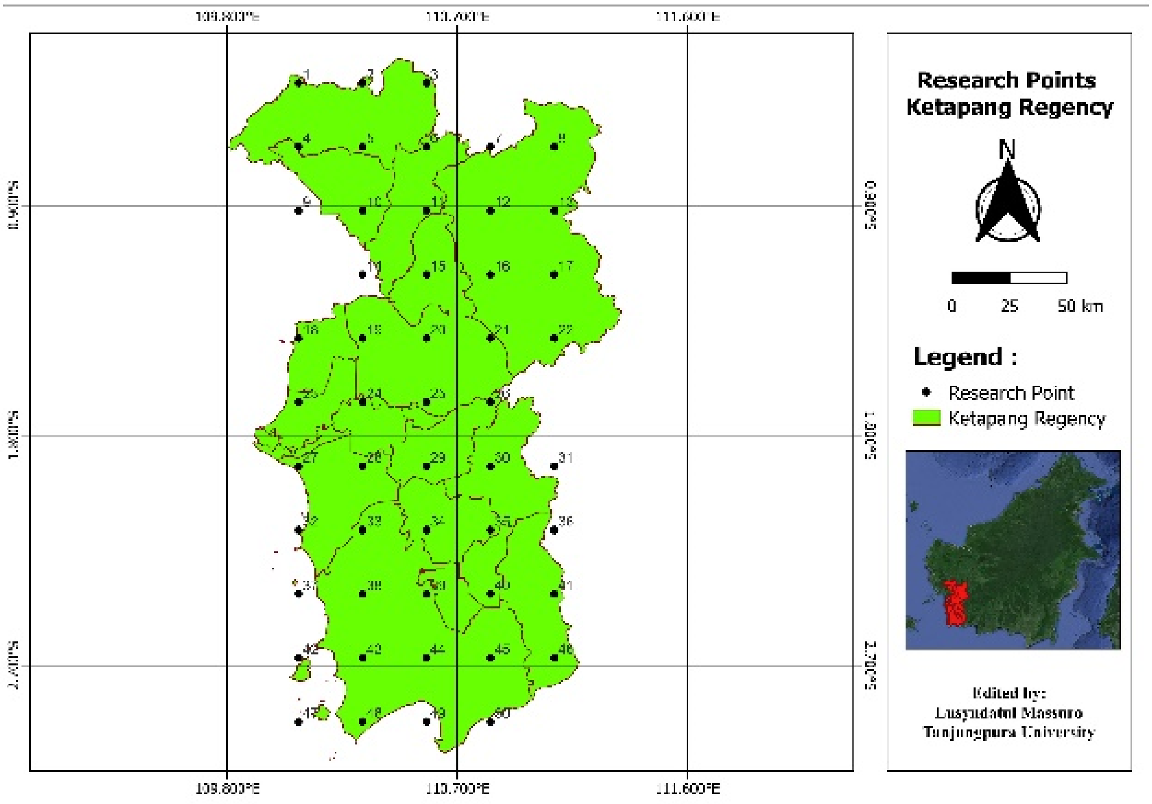

Figure 1. Research location map.

$$KBDI_{today} = KBDI^{t-1} - R_{net} + DF \qquad (1)$$

$$\frac{(203 - KBDI^{t-1})(0.4982e^{(0.0905 \times T_m + 1.6096)} - 4.268) \times 10^{-3}}{1 + 10.88e^{(-0.001736 \times R_0)}} \quad (2)$$

$$R_{net} = \begin{cases} (R^t - 5{,}1), R^t \geq 5{,}1 \text{ mm/day, 1st rainy day} \\ R^t,\ R^{t-1} \geq 5{,}1 \text{ mm/day, 2nd and the next rainy day} \\ 0,\ R^t < 5{,}1 \text{ mm/hari} \end{cases} \quad (3)$$

The calculation of the KBDI method requires 3 (three) parameters, including the accumulation of annual rainfall in the research area, maximum daily air temperature, and accumulation of daily rainfall. Before calculating the KBDI, it is necessary first to determine the initial KBDI value, which is zero. The initial KBDI is determined by assuming that one day after rainfall, it reaches >150 mm within one week. Taufik et al. (2015) have modified the KBDI which is adjusted to the equatorial climate. The KBDI formula can be stated as Equation (1) and (2).

The net rainfall value in Equation (1) can be obtained using the Equation (3).

Description:

KBDI : drought index

$KBDI^{t-1}$: drought index on the previous day

R_{net} : net rainfall (mm)

DF : drought factor

T_m : maximum daily air temperature (°C)

R_0 : annual accumulated rainfall (mm)

KBDI index values are grouped into four levels as in Table 1.

Table 1. KBDI value index (Taufik et al., 2015).

Range of KBDI	Interpretation
0 – 99	Low
100 – 149	Moderate
150 – 174	High
175 – 203	Extreme

Results and Discussion

Analysis of Drought Distribution Based on the KBDI Method

Spatial drought analysis was carried out by mapping KBDI values with QGIS software. Mapping was carried out using IDW interpolation. Figure 2 shows the average monthly drought index value in Ketapang Regency from 2018-2022. The varying colors on the map indicate the drought index value based on four KBDI classifications. Blue is interpreted as a low level of drought, green with a moderate drought, yellow for a high drought, and red as an extreme drought.

Figure 2 in January shows that Ketapang Regency has a low category drought index for all areas. However, it increased to a moderate category from February to March. Entering April, only a small part of Ketapang Regency has a moderate category drought index. In May, Ketapang Regency returned to a low drought category. Some areas in Ketapang Regency began to experience moderate drought when entering June. All regions of Ketapang Regency experienced moderate drought in July. The peak of drought in Ketapang Regency occurred in August with a moderate to high category. The areas experiencing high-category drought are Sungai Melayu Rayak and Pemahan Districts. However, in September, the drought in Ketapang Regency decreased again to a moderate category. In October, some areas entered the low category, but the Kendawangan area was still in the moderate category. Drought in Ketapang Regency was entirely in the low category in November and December.

Ketapang Regency is one of the regions in Indonesia that has a monsoon rainfall pattern. December–January–February is the peak rainfall, and the drought in Ketapang Regency is in the low category. March–April–May is the transition between the wet and dry seasons, so the drought in Ketapang Regency begins to increase. The dry season due to monsoons occurred in June–July–August, so in that month, the drought in Ketapang Regency experienced a high to extreme category of drought. September-October-November is the transition month between the dry season and the wet season. Therefore, that month, the Ketapang Regency drought decreased to a low category. Based on the monthly average, the drought in Ketapang Regency generally has the same pattern, with the moderate to high drought season peak occurring in August and September.

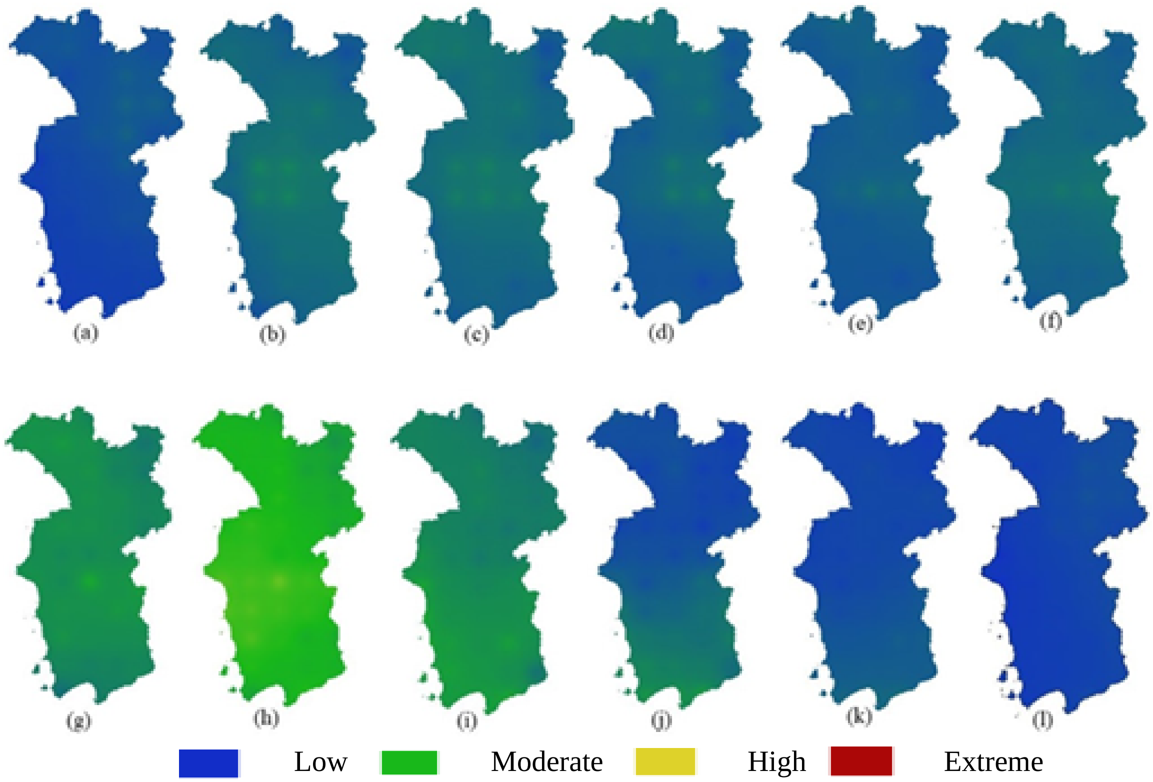

Figure 2. Map of monthly average KBDI distribution for 2018-2022 (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November, (l) December

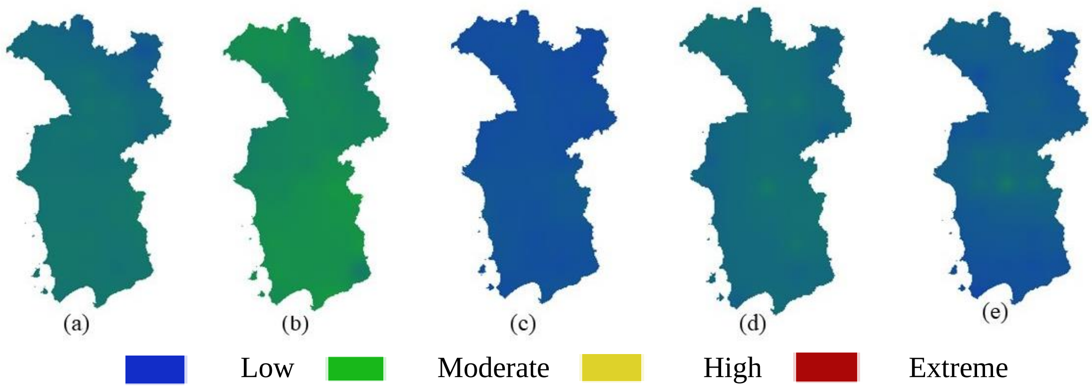

Figure 3. Map of annual average KBDI distribution (a) 2018, (b) 2019, (c) 2020, (d) 2021, (e) 2022

Figure 3 shows a map of the distribution of KBDI in Ketapang Regency in 2018-2022. The year 2018-2022 was chosen because, in the 5-year span, there have been all ENSO phenomena. The annual KBDI distribution map is obtained by averaging the KBDI values from January to December. In 2018, the KBDI distribution map of Ketapang

Regency was in the blue and green range, which means low and moderate drought. In 2019, the entire Ketapang Regency area experienced moderate drought. The drought decreased to the low category in 2020. Entering 2021, Ketapang Regency experienced drought with a dominant moderate category. In 2022, the drought again reduced to the low category, but a small number of areas remained in the mild category. Based on Figures 2 and 3, Ketapang Regency experienced the highest drought in August when entering the dry season and in 2019, the year of the El Niño phenomenon. The results obtained in Figure 3 align with research conducted by Ningsih et al. (2022), which showed that the highest drought in Ketapang Regency occurred in August. This is because the month of August in Ketapang Regency is included in the dry season. The influence of the monsoon is strong on the Ketapang Regency area.

KBDI Analysis of the El Niño Phenomenon

The El Niño is a phenomenon that can cause prolonged drought or dry season characterized by reduced rainfall intensity. The selection of months in the El Niño phase is based on the Oceanic Nino Index (ONI). ONI is one of the parameters often used to monitor El Niño and La Niña events (Nabilah et al., 2017). Figure 4 is a map of the distribution of KBDI values during the El Niño phenomenon from September 2018 to September 2019. Based on Figure 4, drought in Ketapang Regency is in the low category for December-January-February. In the transition months, drought in Ketapang Regency is in the moderate category. The highest drought that occurred during El Niño was in August and September 2019, as shown in Figure 4 (l) and (m). However, in September, there were a small number of areas with a moderate KBDI index. This can happen because September is included in the transition months from dry to wet seasons. In the future, it is necessary to carry out more complex drought studies by adding weather parameters and soil physical parameters for more comprehensive results.

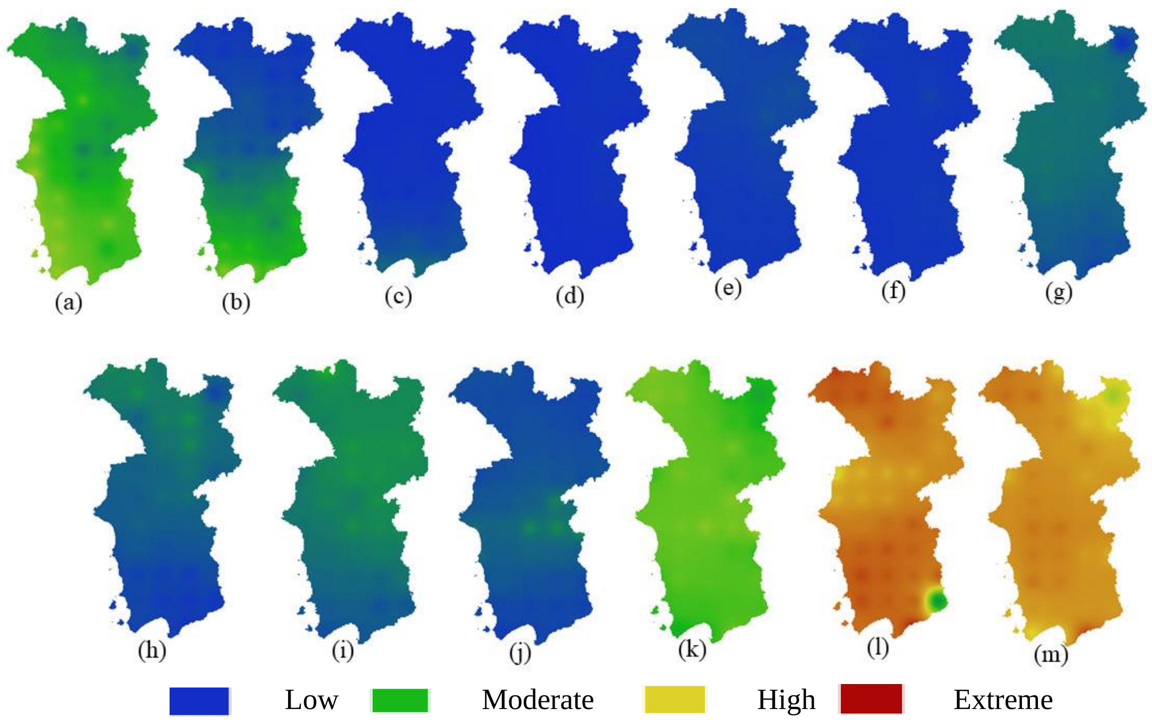

Figure 4. Map of KBDI distribution during the El Niño phenomenon (a) September 2018, (b) October 2018, (c) November 2018, (d) December 2018, (e) January 2019, (f) February 2019, (g) March 2019, (h) April 2019, (i) May 2019, (j) June 2019, (k) July 2019, (l) August 2019, (m) September 2019

The Relationship between KBDI and Hotspot

KBDI and hotspot values aim to determine the relationship between drought and the number of hotspots in Ketapang Regency. Hotspot data was obtained from the MODIS satellite with a high category. Calculations were carried out using Pearson correlation to determine the relationship between KBDI values and the number of hotspots. Pearson correlation is a popular and most frequently used correlation (Purba & Purba, 2022). The function of Pearson correlation is to determine the degree of relationship and contribution of the independent variable with the dependent variable. Pearson correlation is calculated between the average KBDI value for 2018-2022 and the number of hotspots in the same year. The correlation value obtained in that year was 0.88, which means it has a solid relationship. This shows that the number of hotspots will also increase with an increase in the KBDI value.

Based on Figure 5, the highest KBDI value was in 2019 followed by the largest number of hotspots. The phenomenon that occurred in 2019 was El Niño which of course had an impact on drought. In 2018, a normal year followed by the beginning of El Niño, the number of hotspots detected during one year was approximately 300. The KBDI value decreased in 2020, and the number of hotspots also decreased. In 2020, it was a transition year from normal to La Niña. The La Niña phenomenon occurred throughout 2021 and 2022, so the KBDI value was low, and the number of hotspots detected was not significant.

Figure 6 shows the relationship between the average monthly KBDI in 2018-2022 and the accumulation of monthly hotspots. The correlation value based on the average monthly KBDI value and the number of monthly hotspots is 0.57, which has a reasonably strong relationship. A small number of hotspots will follow low KBDI values from January to June; even in May, no hotspots were detected. The KBDI value and the number of hotspots began to increase in July, with the highest KBDI value in August. However, the most significant number of hotspots was in September, reaching 1.638, while the KBDI value in September was 66.11, which is included in the low category. An increase does not always follow an increase in the KBDI value in the number of hotspots (Tsabita, 2023). This can happen because hotspots can come from other factors, such as forest fires caused by humans. The KBDI value decreased from October to December, followed by several hotspots.

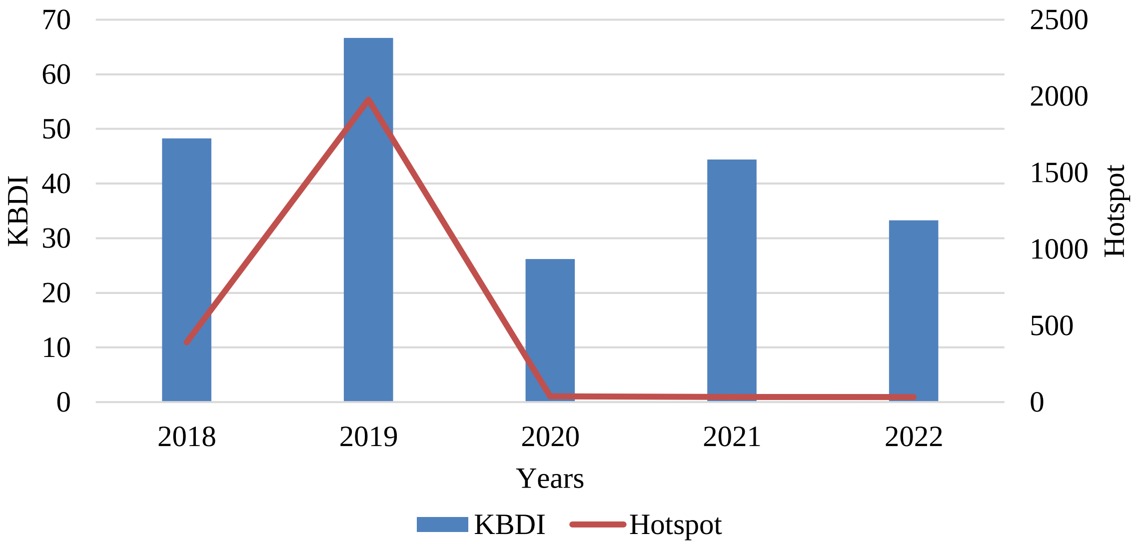

Figure 5. Graph of the relationship between KBDI and the number of annual hotspots.

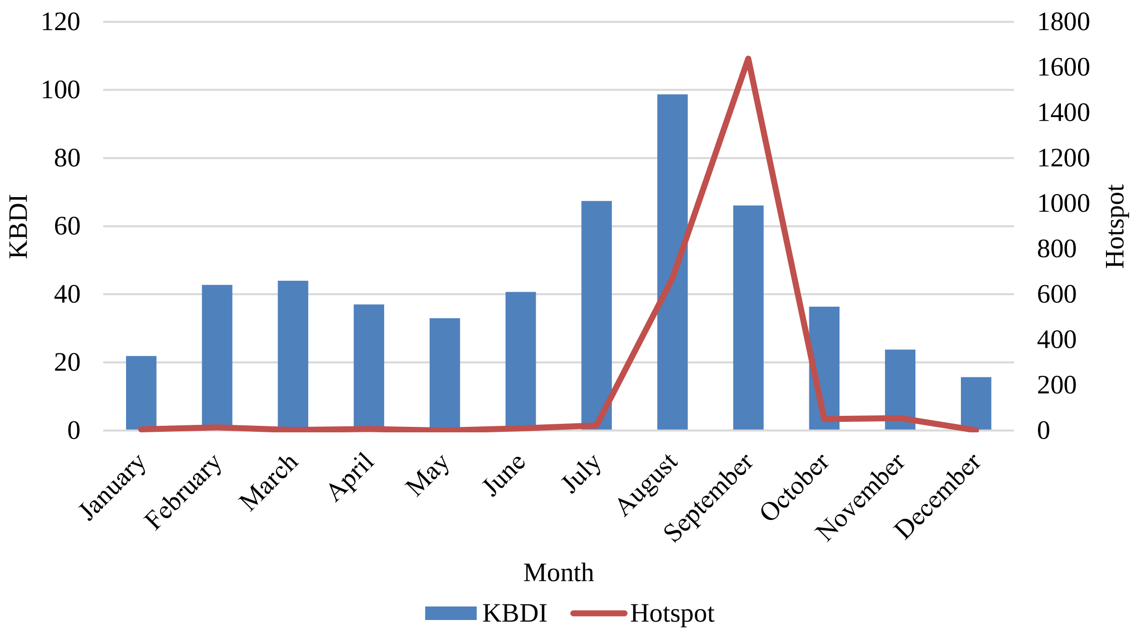

Figure 6. Graph of the relationship between KBDI and the number of monthly hotspots.

Figure 7 shows the relationship between the KBDI value and the number of monthly hotspots from 2018-2022. Based on Figure 7, the highest KBDI value occurred in 2019, followed by the most significant number of hotspots. The correlation coefficient between KBDI and the number of hotspots of 0.61 is classified as having a solid relationship. Drought in the Ketapang region is quite influenced by meteorological phenomena such as monsoons and ENSO, this can have an impact on the level of drought in the Ketapang region, thereby increasing the chances of forest and land fires.

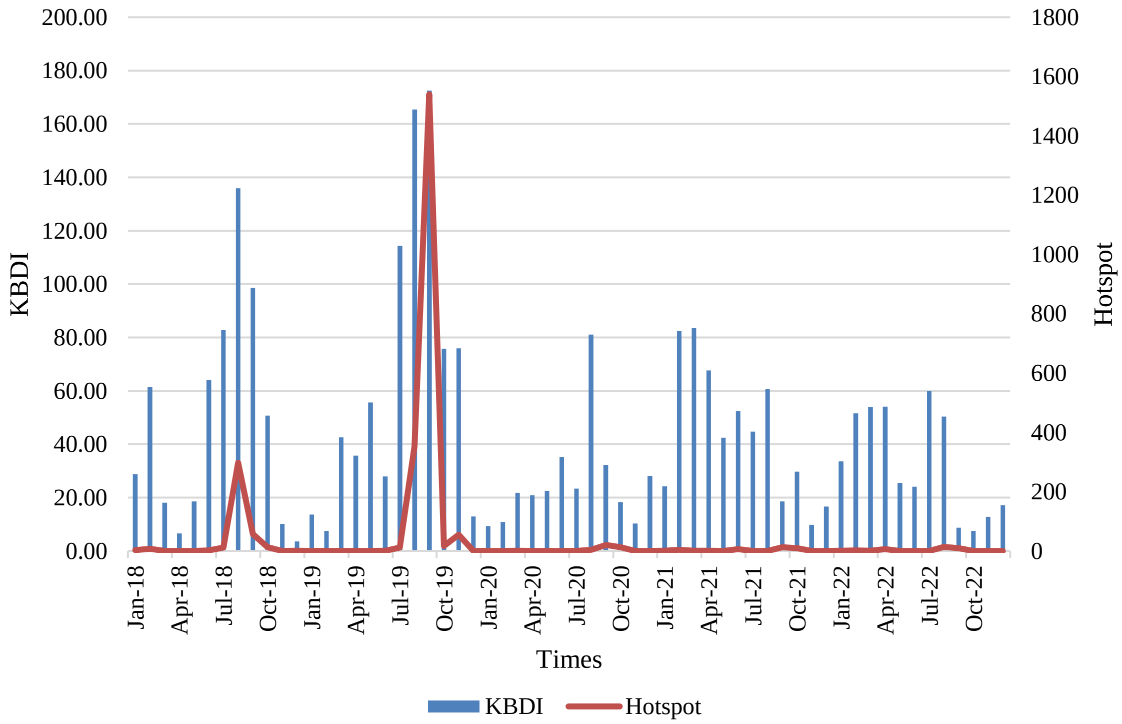

Figure 7. Graph of the relationship between KBDI and monthly hotspots from 2018-2022.

Conclusion

Based on the research that has been conducted, the conclusion that can be drawn from this study is that the level of drought that occurs in Ketapang Regency based on the monthly average has a low category from January to May. Drought began to increase in June, with the peak of drought occurring in August, and began to decline again in October. Based on the annual average, Ketapang Regency experienced the highest drought in 2019 when the El Niño phenomenon occurred. In the El Niño phase, August 2019 and September 2019 had the highest level of drought with a high to extreme category. In addition, the relationship between the KBDI value and the number of hotspots has a robust correlation, with a correlation value of 0.88, so the higher the KBDI value, the more hotspots will be followed.

Author Contribution

Lusyndatul Massuro conducted reference collection, data collection, data processing, and analysis. Riza Adriat and Muliadi supervised the interpretation of results and discussion. Andi Ihwan and Yuris Sutanto supervised the improvement of the writing.

Conflict of Interest

The authors declare no conflict of interest.

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