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Drought Analysis On Ngawi District West Jawa Using The Standardized Precipitation Index (Spi) Method Based On Rainfall Data 2012 To 2021

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Abstract – Changes in Pacific Ocean and Indian Ocean temperatures can trigger climate change, one of which is El-Nino. Ngawi Regency, East Java, Indonesia is one of the areas frequently affected by drought, which is thought to be caused by El Nino. This research was conducted to determine the distribution of drought in the Ngawi district. The method used is the Standardized Precipitation Index (SPI) and the data used is monthly rainfall data. The mapping uses ArcGIS 10.5 software with IDW (Inverse Distance Weight) interpolation. The results obtained are that the maximum drought conditions in Ngawi Regency occurred in 2015, with a very dry category. The area with the highest frequency of droughts is Jogorogo District with 36 times. The ENSO correlation value for drought is 5.1%.

Keywords – drought, Ngawi, SPI, rainfall

I. INTRODUCTION

ENSO is a phenomenon of the interaction between the sea's surface layers and the Pacific Ocean's atmosphere. This interaction causes climate variations in the world. The cause of ENSO is that there is a deviation (anomaly) in the Pacific Ocean's Sea Surface Temperature (SST) to the normal average temperature. The ocean component of ENSO, namely La Niña and El Niño, the Southern Oscillation is the atmospheric component. El Niño is a condition when there is an increase in SST in the equatorial Pacific Ocean from the normal temperature, while La Niña is a condition when there is a decrease in SST in the equatorial Pacific Ocean from the normal temperature [1].

The one cause of drought is a global climate anomaly. Climate anomaly that occurs continuously has their own impact on people's lives, such as increasing rainfall intensity, long dry seasons, increase in water volume due to the melting of polar ice caps, the occurrence of tornadoes and natural disasters, and reduced water resources. Drought is a natural phenomenon that occurs due to global climate change. The atmospheric circulation in the Pacific Ocean region is one of the triggers for El Nino. El Nino is one of the causes of drought.

Generally, Drought is grouped into meteorological, hydrological, and agricultural droughts. Each type of drought has different parameters. One method that can be used to analyze meteorological drought is the Standardized Precipitation Index (SPI) method. SPI (Standardized Precipitation Index) is an index value that is used to determine the deviation of rainfall values from normal over a long period [2]. The developer of the SPI method is to create a model for measuring the rainfall deficit in various periods against normal rainfall conditions [3]. The SPI method is used to determine the level of drought in an area, for a long or short period of time by utilizing statistical data. The SPI (Standardized Precipitation Index) method is a method used to see the level of drought in a region. The drought level is analyzed based on the value of the surplus deficit [4].

Indonesia is located on the equator causing two seasons, the rainy season and summer. The duration of the rainy and summer seasons often changes depending on weather conditions. Longer summer duration and decreasing rainfall quantity can cause drought. Some areas in Indonesia are often in drought conditions. The drought that occurs is often thought to be caused by El Nino, even though there are several other causes, not always caused by El Nino.

One region in Indonesia that often occur drought is Ngawi Regency, East Java Province. Geographically, Ngawi Regency is located at 7◦21' – 7◦31' S and 110◦10' - 111◦40' E. Part of the Ngawi area is located on the slopes of Mount Lawu. Based on the calculation of the average monthly rainfall in Ngawi in 2020, a value of 18.11 mm/month is obtained [5]. This value indicates that Ngawi Regency is at a dry level [6]. The Ngawi Regency Regional Disaster Management Goverment published that there had been a drought in 43 villages [7]. The drought that occurs in many villages and is repeated, is necessary to conduct research on the effect of weather anomalies on the drought that occurs in Ngawi. Mapping of drought areas is needed for mitigation in anticipation of a drought that might happen again. Some researchers use the SPI method to identify drought levels in some regions in Indonesia, and the result can be used as a suggestion for drought mitigation [8]. The purpose of this research is to map the distribution of drought in Ngawi Regency over 10 years (2012 to 2021) using the SPI method and calculate the value of the ENSO contribution to drought in Ngawi Regency.

II. METHOD

Ngawi Regency is located in the western region of East Java Province and is directly adjacent to Central Java Province. The total area of Ngawi Regency is 1,298.58 km2. Geographically, Ngawi Regency is located at 110°10' - 111°40' E and 7°21' - 7°31' S. About 39% or 504.76 km2 of the Ngawi Regency area is rice fields. In accordance with the Regional Regulation in 2004, the Ngawi Regency area is divided into 19 sub-districts and 217 villages. The topography of the Ngawi Regency area consists of highlands and flat land. There are 4 districts located on the plateau of Mount Lawu namely Sine, Ngrambe, Jogorogo, and Kendal. The map of the research area is as Fig. 1. This study uses secondary data consisting of SOI data and monthly rainfall data from the Meteorology and Geophysics Government of Ngawi Regency. The rainfall and SOI data period were from January 2012 to December 2021. The rainfall data includes 15 rainfall stations, the data belong to the Indonesian Government of Meteorology and Climate. SOI data uses BOM (Bureau of Meteorology) data, which is obtained through the website www.bom.gov.au.

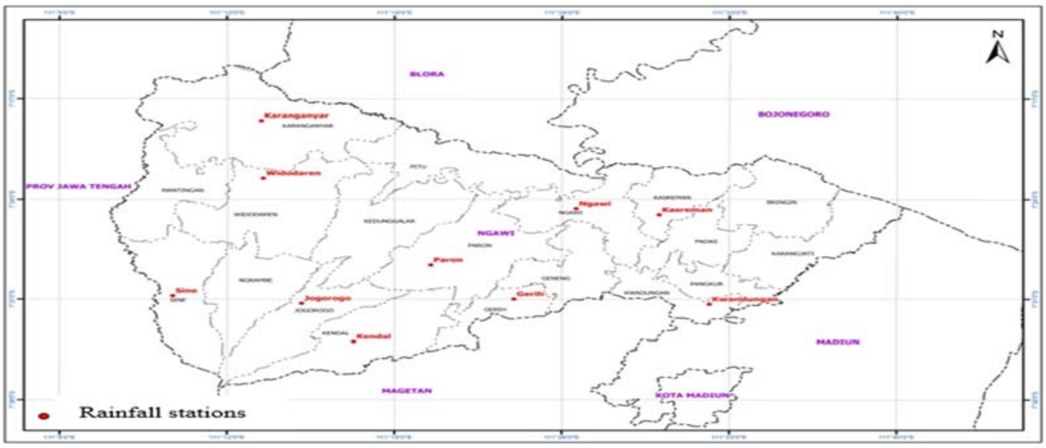

Figure 1. Rainfall Stations map on Ngawi Regency

Standardized Precipitation Index (SPI)

The calculation of rainfall uses the SPI (Standardized Precipitation Index) method which was developed based on the calculation of water deficits at various time durations and transformed into a drought index scale [9]. This method is able to classify the level of drought in an area with a different climate over a long or short period of time because it uses consistent statistical data. McKee et al carried out a classification to identify drought intensity, and criteria for drought events in certain periods [10]. The time of occurrence of drought can be seen from the SPI value, if the SPI value is -1 or less it indicates that drought intensity has reached and a positive SPI value indicates the end of the drought period [11]. The SPI index values and classifications listed in Table 1 by McKee are as follows:

Table 1. SPI level

SPI value	level
≥ 2	Extreme wet
1,50 s/d 1,99	Wet
1,00 s/d 1,49	Moderate Wet
-0,99 s/d 0,99	Normal
-1,00 s/d -1,49	Moderate drought
-1,50 s/d -1,99	drought
≤ -2	Extreme drought

(Reference : McKee,2013)

The SPI value is calculated according to the number of gamma distributions, by the following formula [12]:

$$G(x) = x \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} dx \tag{1}$$

Equation (1) is a gamma probability function of the frequency distribution of the amount of rainfall for each station in the SPI calculation. Γ(α) is the defined Gamma function:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{y} dy \tag{2}$$

$$\alpha = \frac{1}{4A}\left[1 + \sqrt{1 + \frac{4A}{3}}\right] \tag{3}$$

$$\beta = \frac{\bar{x}}{\alpha} \tag{4}$$

$$A = \ln \bar{x} - \frac{\sum \ln x}{n} \tag{5}$$

$\alpha > 0$ is the shape parameter, $x > 0$ is the total monthly rainfall, $\beta > 0$ is the scale parameter, and n is amount of data

$$H(x) = q + (1 - q)G(x) \tag{6}$$

q is the probability of the amount of rainfall having a value of 0. The cumulative probability of H(x) is converted into a Z value with a normal standard distribution with an average value of 0 and a variation of 1.

When $0 < H(x) < 0,5$

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 d_2 t^2 + d_3 t^3}\right), t = \sqrt{\ln\left(\frac{1}{H(x)^2}\right)} \tag{7}$$

When $0,5 < H(x) < 0$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 d_2 t^2 + d_3 t^3}\right), t = \sqrt{\ln\left(\frac{1}{1 - H(x)^2}\right)} \tag{8}$$

Where c_0 = 2,515517; c_1 = 0,802853; c_2 = 0,010328; d_1 = 1,432788; d_2 =0,189269; d_3 = 0,001308.

Based on the SPI value, mapping was carried out to determine drought distribution in Ngawi Regency. Regional drought mapping using ArcGIS software. Administrative boundaries of the study area use digital HD map data for Ngawi Regency. The interpolation used IDW (Inverse Distance Weight) method, IDW method produces a better interpolation value than the Kriging and Spline methods [13].

Southern Oscillation (SOI)

The SOI value is used for the benefit of monthly climatological analysis. SOI values on a daily or weekly scale can be affected by daily weather patterns. El Nino and La Nina intensity levels: If the SOI value is -5 to 0, for at least 3 months, then El Niño is weak. The SOI value is -10 to -5 for at least 3 months, then El Nino is moderate. If the SOI value is greater than -10 for at least 3 months, then El Nino is strong. If the SOI value is +5 to +10 for at least 3 months, then La Nina is weak. If the SOI value is greater than +10 for at least 3 months, then La Nina is strong.

The difference in air pressure in the Pacific Ocean triggers rain which affects the climate in various regions. The difference in air pressure is called SOI. Based on the SOI value from 2012 to 2021, it can be seen the relationship between climate conditions in the Pacific region and the research location. There are 2 stages used to analyze the relationship between SPI and SOI. The first stage is to see the similarity of trends between SPI and SOI after normalization [14]. The second stage is using SPSS software. SPSS is used to determine the relationship between SPI and SOI by utilizing a simple linear regression method. The regression value represents the relationship between ENSO and drought. The results of simple linear regression on SOI and SPI are in the form of model summary tables and coefficient tables [15].

III. Result And Discussion

An example of the SPI calculation results in 1 year is shown in Table 3. This study produced 10 SPI calculation tables by year. From the results, we can calculate the frequency of drought events in each region in 10 years. The drought frequency based on SPI calculation is shown in Table 2. The SPI results are also mapped as shown in Figure 3. Mapping is done every month to find out the distribution of drought in Ngawi.

Analysis of drought events is carried out on a spatial scale, to find out which areas have the potential for drought. The results of the SPI calculation showed that the highest frequency of drought occurred in Jogorogo District with 36 incidents, while the fewest drought events occurred in Widodaren and Kedunggalar Districts with 4 incidents. Table 2 also informs that the frequency of drought events in Ngawi Regency occurs unevenly, this is evident from the significant difference in the number of droughts that occur between one sub-district and another.

Ngawi Regency is one of the areas with a long duration of drought each year. Based on the results of processing rainfall data from 2012 to 2021, Ngawi Regency has the potential for drought and in several areas, drought is in the extreme category. Fig. 2. is a drought map in Ngawi Regency over a 10 years period (2012 to 2021). Within 10 years, various drought conditions have occurred which are categorized as moderate dry, very dry, and extremely dry. The results of the SPI calculations are mapped as shown in Figure 2 as an example, it appears that several areas have experienced drought several times. The results of the SPI produced 120 maps which are shown in Figure 2. These are choices based on the drought events that have occurred.

Table 2. Drought Frequency in Ngawi Recency, based on rainfall stations data from 2012 to 2021

No.	Distric	Drought Frequency			
		Moderate drought	drought	Extreme Drought	Total
1	Sine	11	4	2	17
2	Jogorogo	21	7	8	36
3	Kendal	7	2	3	12
4	Ngawi	4	1	1	6
5	Widodaren	4	0	0	4
6	Kasreman	11	2	0	13
7	Gerih	6	1	0	7
8	Kwandungan	4	1	0	5
9	Paron	6	1	0	7
10	Mantingan	4	1	1	6
11	Padas	7	1	1	9
12	Karangjati	10	4	1	15
13	Ngrambe	9	7	0	16
14	Pitu	4	2	1	7
15	Kedunggalar	4	0	0	4

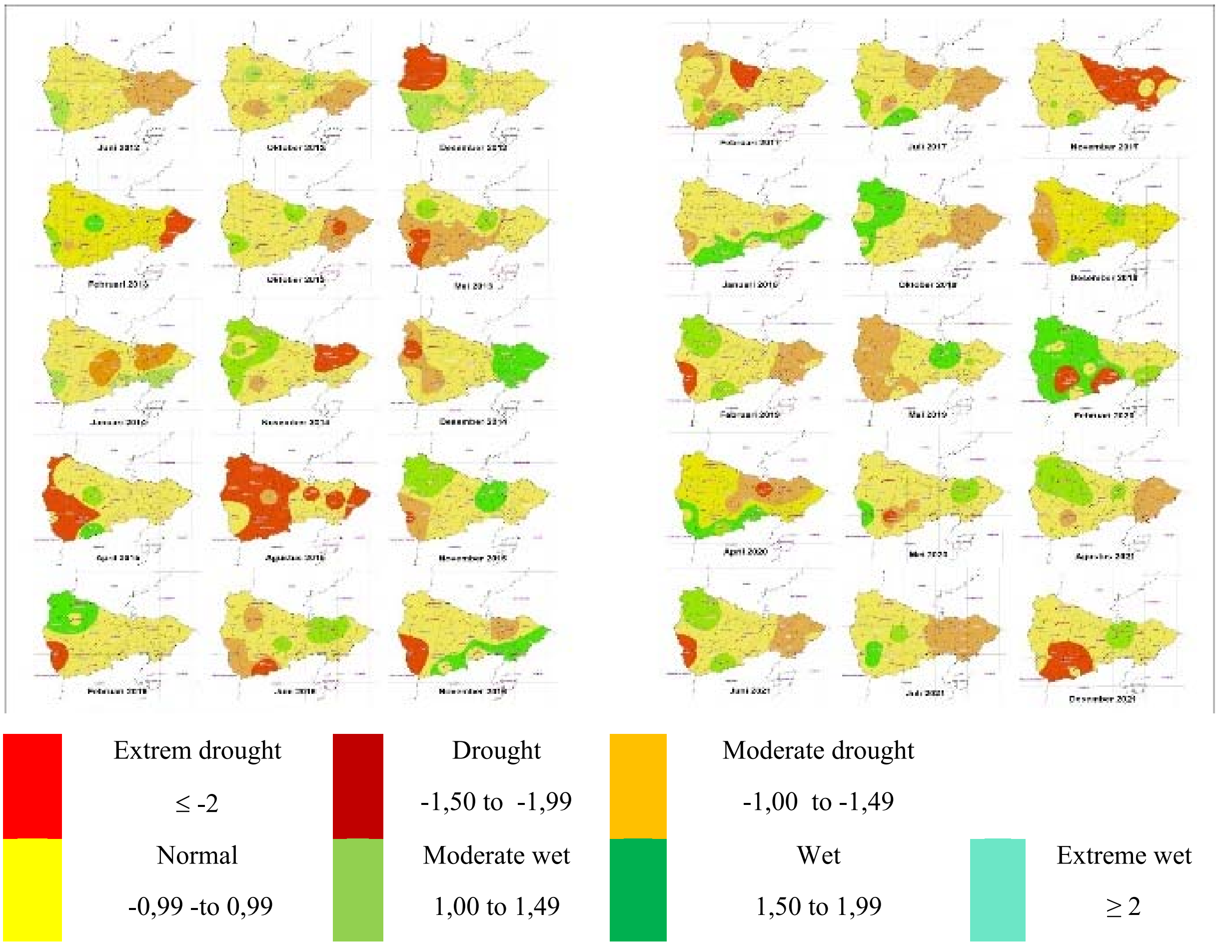

Figure 2. The drought map in Ngawi Regency in 10 years (2012 to 2021).

The maximum drought in Ngawi Regency for 10 years is from 2012 to 2021, occurring in August 2015 with an extreme drought level that occurred in almost all areas of Ngawi Regency. Fig. 3 shows the maximum drought conditions in August 2015. Based on the 2015 SPI value calculation, the maximum drought in 2015 occurred in April, August, and November. The SPI calculation in 2015 is shown in Table 3.

Table 3. SPI calculation in 2015

Stasiun	Tahun 2015											
	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Agust	Sept	Okt	Nov	Des
Sine	1,52	0,06	0,40	0,56	2,92	-0,33	0	-0,87	0	0	-1,75	-1,01
Jogorogo	-0,44	0,58	-0,70	-1,63	-0,51	-0,33	0	-17,5	0	0	0,37	-0,76
Kendal	0,97	1,78	2,13	1,57	-0,35	3,00	0	-18,2	0	0	0,46	0,21
Ngawi	-0,29	-0,30	-0,43	0,16	-0,44	-0,33	0	-62,3	0	0	1,66	0,67
Widodaren	0,18	-0,63	0,57	0,36	0,08	-0,33	0	-16,7	0	0	1,14	-0,71
Padas	1,11	0,15	-1,12	-0,85	-0,56	-0,33	0	-72,6	0	0	0,58	-0,01
Karangjati	0,65	1,49	0,54	0,36	0,11	-0,33	0	-18,3	0	0	-0,79	0,22
Ngrambe	-1,37	-1,59	-1,64	-1,54	-0,21	-0,33	0	-0,60	0	0	-1,21	-1,64
Pitu	-0,89	-0,91	0,05	-0,80	-0,52	-0,33	0	-18,7	0	0	-0,31	1,75
Kedungalar	-1,45	-0,64	0,20	1,09	-0,51	-0,33	0	-1,27	0	0	-0,51	1,27

In April 2015, the drought value of 1 to 1.49 was included in the moderate wet category. The area in this category is Kedunggalar District. The drought value of 1.5 to 1.99 is the wet category. The wet category area is in Kendal District. The drought value -1.5 to -1.99 is the extreme drought category that occurs in Jogorogo and Ngrambe Districts. In August 2015, Kedunggalar District experienced a drought with a value of -1 to -1.49 is in a moderate drought level, while drought value of -1.5 to -1.99 extreme drought occurred in Jogorogo, Kendal, Ngawi, Widodaren, Padas, Karangjati, and Pitu. In November 2015, a drought value of 1 to 1.49, moderate wet, occurred in Widodaren District, which a drought value of 1.5 to 1.99 is a wet level occurred in Ngawi District, whereas a value of -1 to -1.49 moderate drought level occurred in Ngrambe District. The drought value of -1.5 to -1.99 is the extreme drought level that occurs in Sine District. The drought level in 2015 was mapped in Fig. 3.

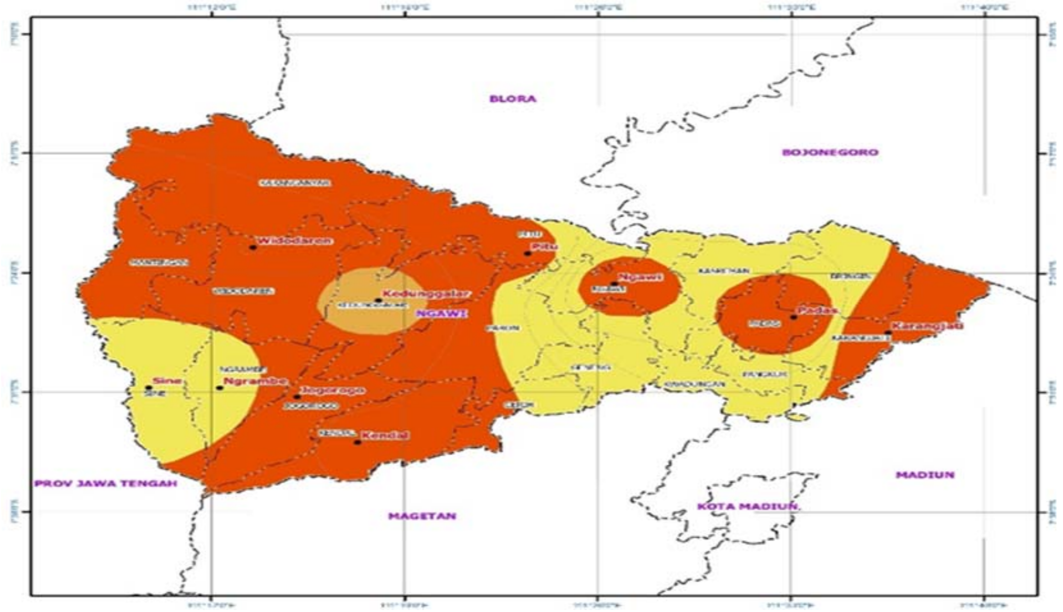

Figure 3. Based on the SPI method, the Drought Map of Ngawi Region uses rainfall data in August 2015 (red is extreme drought, orange is moderate drought, and yellow is normal condition)

The search for the relationship between ENSO and drought events in Ngawi District was carried out by comparing SOI and SPI and then matching the trends between the two. Figure 4 is a trend graph between SOI and SPI in Ngawi Regency from January 2012 to December 2021. Based on the graph in Fig.4, it can be seen that not all trend lines have the same trend, some of the same trend lines are found on the circled line. Based on the SOI and SPI comparison chart, it is known that SOI and SPI have a weak relationship.

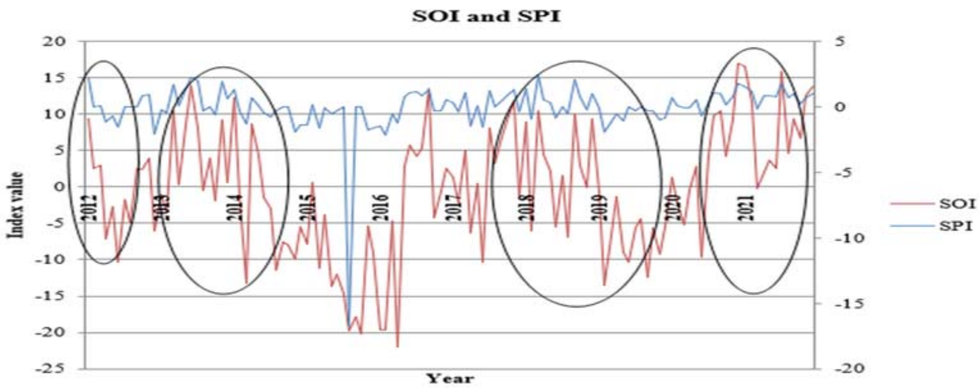

Figure 4. SOI and SPI indekx value

Validation of the level of relationship between SOI and SPI was carried out using the regression method and T-test. T-test results are shown in Table 4 and Table 5.

Table 4. T-test

Model	B	T	Signifikansi
Constant	-1,05	-0,528	0,599
SOI	0,059	2,514	0,013

The T-test result is 2.514 which is positive, this shows that the relationship between SPI and SOI is a unidirectional relationship, which means that if the SOI value is positive, the SPI value is also positive and vice versa.

Table 5. Regression test

R	R *Square*
0,225	0,051

A good level of significance (α) in research is around 5% or 0.05. The significance level obtained in the calculation will be compared with 0.05. If α calculation is less than 0.05 then there is a relationship between SOI and SPI, and vice versa if α calculation is greater than 0.05 then there is no relationship between SOI and SPI [18]. Based on regression calculation, the R square value is 0.051. It indicates that the effect of SPI on SOI is 5.1%, while 94.9% is influenced by other variables. Then, an R-value of 0.225 indicated that between SPI and SOI there was a weak correlation. So, it can be concluded that the contribution value of ENSO to drought is 5.1%.

ENSO is one of the causes that affect rainfall in Ngawi but is not the main cause of the drought. Another cause of drought that occurs can be due to geological conditions. Ngawi Regency has a geological structure that is divided into two sides, those are the south side and the north side. On the south side, the geological structure is in the form of a fault structure, which is located in the Lawu volcano area, while on the north side, the geological structure is in the form of folds and there are shear and upward faults. Because the structure is in the form of a fault and is still in the vicinity of the Lawu volcano, it can increase the temperature in the Ngawi Regency area. That's why geological conditions can be one of the causes of drought in Ngawi Regency [19] [20] [21].

IV. Conclusion

The maximum drought in Ngawi occurred in 2015 with a very dry category. In 2021 there were 4 times of droughts in 1 year. The Ngawi Regency area most often affected by drought is Jogorogo District with a frequency of 36 droughts in 10 years. The contribution value of ENSO to drought in Ngawi Regency is 5.1%, so it has a weak correlation with ENSO. The drought that occurs is also caused by topography and soil types in the Jogorogo region.

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