The Climate Change Impact on Drought Characteristics in North Lombok Regency

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The Climate Change Impact on Drought Characteristics in North Lombok Regency

Humairo Saidah[1*], Lilik Hanifah[1], I Dewa Gede Jaya Negara[1]

[1] Civil Engineering Department, Faculty of Engineering, University of Mataram, Mataram,

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Correspondence Author:
Humairo Saidah
h.saidah@unram.ac.id

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Abstract: Lombok Island is part of Indonesia which has a high vulnerability to drought. The area that often experienced drought severely on Lombok Island is North Lombok Regency. This study wants to examine the effect of climate change on drought characteristics in this region using the standardized precipitation index method using four rain stations in the North Lombok region rainfall recording data of 20 years (1999-2018). The analyses were taken into two groups of a 10-year time scale, 1999-2008 and 2009-2018, to overview both of the 10-years drought characteristics. Drought index values were observed on a period of 1-month (SPI1), 3-months (SPI3), and 6-months (SPI6) to get the map of drought duration, drought magnitude, drought intensity, and relative frequency. The results show that the drought characteristics in Lombok showed a decrease significantly in all measurement parameters used. The SPI3 results have shown the drought duration was decreasing in the last 10 years by 87%, from 2,43 to 0.03 months. The strength of the drought decreased by 88%, from -1.03 to 0.12 (severely dry to normal). Then the drought intensity became lower up to 87% from -0.22 to -0.03 monthly, and the relative frequency of drought events decreased by 83%. Signs of the decline were further followed by the same decreasing trends in the 6-month drought index, SPI6. The decrease in the drought parameter index illustrates that climate change impact has reduced the risk of drought disaster on the island of Lombok in the future.

Keywords: Climate Change; Drought Index; SPI; Drought magnitude; Drought Intensity

Introduction

The world is coping the global climate change as one of the most significant issues today and future generations. Climate change can alter the character of drought, such as the magnitude, frequency, and duration of drought, especially in a semi-arid region. This study investigated the impact of climate change on the severity, duration, and frequency of drought in the island of Lombok, especially North Lombok, one of the regions in eastern Indonesia that often experience a water shortage.

A drought is a natural event indicated by the limited availability of water reserves above, on the surface and the ground, both for agricultural activities and human needs. Drought is a factor inhibiting the growth of agricultural production, especially rice as a staple food, which can affect local and national economies. A drought is also defined as a time when a region experiences below-normal precipitation. The lack of adequate rainfall can cause reduced soil moisture or groundwater, diminished streamflow, crop failure, and a general water shortage.

Drought was distinguished into four distinct types (Wilhite & Glantz, 1985). First, meteorological drought is dryness caused by a decrease in precipitation relative to the average rainfall for a given region and period. Second, agricultural drought is notified by a deficit of soil moisture content resulting in a lack of water supply to crops. Third, hydrological drought, which is shown by streamflow deficits, results in low water levels in rivers, lakes, and reservoirs. Fourth, Socioeconomic drought is caused by a decrease in rainfall relative to the average one for a period and region. Recently, a groundwater drought has been proposed to be added as a fifth type of drought (Mishra & Singh, 2010).

Climate change confirmed increases in extreme climate events, and droughts may be rising in frequency, intensity, and duration (Peterson et al., 2013; Wilhite et al., 2014). Drought consequences have increased dramatically in both developing and developed countries as a direct result of increased drought

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frequency, intensity, and length, as well as a narrowing of the gap between water availability and demand. Although agriculture has traditionally been the first and most affected industry, many other industries have suffered substantial losses, including energy production, tourism and recreation, transportation, urban water supply, and the environment (Wilhite et al., 2014).

Numerous research has examined how climate change affects extreme hydrological occurrences (Lamonda & Penning-Rowsell, 2014). However, most research has focused on how climate change affects floods, but there has been limited research on the interaction between drought and climate change at the watershed scale (Hosseinizadeh et al., 2015; Shi et al., 2013).

To know how drought can affect on economy and society, drought characteristics such as duration, intensity, and severity, have to be considered (Field et al., 2012). This study has examined the impact of climate change on the spatial and temporal variability of drought at the four sites in North Lombok, Indonesia. Furthermore, it assessed the intensity, duration, and frequency for the latest 20 years (1999-2018) using the Standardized Precipitation Index (SPI) method utilized in two periodical ranges ten years long to compare the drought characteristics.

Method

Study Area and Data Used

The study was conducted in the North Lombok Regency, one of the regencies in West Nusa Tenggara Province, Indonesia. It has an area of 776.25 km² and is geographically located at the northern foot of Mount Rinjani, directly adjacent to the Java Ocean on the other side North, East Lombok Regency in the East, West Lombok Regency and Central Lombok Regency in the South and the Lombok Strait and the Regency of West Lombok in the West (Fig 1).

Figure 1. North Lombok Regency

Daily rainfall data for North Lombok Regency were collected in the latest 20 years (1999-2018). There are four rain stations spread over the Regency namely: Santong, Tanjung, Sopak, and Gunung Sari (Table 1).

Table 1. Rain station over North Lombok

Rain Station	Longitude	Latitude	Elevation
Santong	1160 17' 24"	080 19' 18"	+361,49 m
Tanjung	1160 09' 36"	080 21' 36"	+ 20 m
Sopak	1160 25' 09"	080 16' 29"	+209.09 m
Gunung Sari	1160 05' 52"	080 32' 25"	+138,07 m

Method of completing missing data

In many areas, the rain data recorded is sometimes incomplete due to administrative and human errors or recording equipment damage, then completing data must be done by estimation technique. Ideally, estimating missing data is carried out by comparing the data from several next stations and the correlation with the test station (Adhyani et al., 2017).

In this study, completing the missing rain data was carried out by a normal ratio method, a simple method to fill in the missing rainfall data based on rainfall data from several close stations simultaneously and compared it with the annual rainfall data of each station. The formula for completing missing data at stations is (De Silva et al., 2007):

$$P_x = \frac{1}{m}\sum_{i=1}^{m}\left[\frac{N_x}{N_i}\right]P_i \quad (1)$$

Where: Px = estimated value of rainfall for the ungauged station (mm); Pi = rainfall values of other rain gauges used for estimation; Nx = Normal annual rainfall data for the ungauged station; Ni = normal annual precipitation of other surrounding stations; m is the number of surrounding stations.

Calculating the Standardized precipitation index

The SPI is a monthly statistical indicator given as an indexing of drought level that compares cumulated precipitation during a time of n months to the long-term cumulated averaged rainfall for the same location and accumulation period. It was first proposed by McKee et al. (1993) as a unique measurement of the precipitation deficit based on its probability (Spinoni et al., 2014). SPI is appropriate for measuring short-term impacts on soil moisture, snowpack, and stream flows of small rivers when computed over a short time scale (up to 3 months). SPI is also related to medium-term cumulated values (3–12 months, i.e., SPI3 to SPI-12) that are suitable for measuring the impact on streamflow and reservoir storage. SPI also has the best performance in long-term process assessment, such as groundwater recharge (McKee et al., 1993).

For many reasons, SPI was chosen as the basis for computing drought-related components (Spinoni et al., 2014). First, it is simple and easy to calculate and requires only rainfall data inputs Agnew (2000) second, SPI gives a flexible indicator with excellent spatial coherence; third, it is extensively used and approved in worldwide drought studies. SPI is the most popular on the list of drought index methods in terms of resilience and reliability (Heim, 2002; Spinoni et al., 2014). Many countries have used the SPI method in their national meteorological services for drought monitoring studies, such as the U.S. Drought Monitoring Center (Svoboda et al., 2002) and the European Drought Observatory (Vogt et al., 2011). SPI calculation includes matches probability density function of Gamma distribution defined by:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(a)}\int_0^x t^{a-1}e^{\frac{-x}{\beta}} \quad (2)$$

Where α> 0 is the form parameter; β> 0 is a scale parameter described as a ratio of mean monthly rainfall by α; and x> 0 is the total monthly rainfall. While Γ (α) is defined as:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1}e^{-y}dy \quad (3)$$

The estimation of α and β values for each rain station using this formula:

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

$$\beta = \frac{\bar{x}}{\alpha}\text{; and } A = ln(\bar{x}) - \frac{\sum ln(x)}{n} \quad (5)$$

Where n is the number of rainfall data. Then calculate the cumulative probability and the Gamma spread integrated with x to give G (x):

$$G(x) = x\int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(a)}\int_0^x t^{a-1}e^{\frac{-x}{\beta}}dx \quad (6)$$

Then substitution of $I = \frac{x}{\beta}$, so the formula (6) becomes:

$$G(x) = \frac{1}{\Gamma(a)}\int_0^x t^{a-1}e^{-t}dt \quad (7)$$

The gamma function is undefined for x = 0. Then the value of G (x) becomes:

$$H(x) = q + (1-q)G(x) \quad (8)$$

Where: q = m/n; m is the number of rainfall events of 0 mm in the rain data series. SPI value calculation:

$$Z = SPI = -\left(t - \frac{C_0+C_1t+C_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right);\ \text{for } 0 < H(x) \le 0.5 \quad (9)$$

And transformation of gamma distribution:

$$t = \sqrt{ln\left[\frac{1}{(H(x))^2}\right]}; \quad (10)$$

$$Z = SPI = +\left(t - \frac{C_0+C_1t+C_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right);\text{for } 0.5<H(x)\le 1.0 \quad (11)$$

The SPI classification index describes a relative moisture condition within 9 (nine) categories(McKee et al., 1993), especially a drought event of the time scale, with the index value reaching -1 or less, as shown in Table 2.

Table 2. The SPI Drought classification

SPI	Class
-0.99 to -0.5	Mild drought
-1.49 to -1.00	Moderately drought
-1.99 to -1.50	Severely drought
≤ -2.0	Extremely drought

The Duration, Drought Magnitude, Intensity, and Relative Frequency of Drought

Drought duration refers to the length of time since the drought began or the length of time from the beginning of a historic drought occurrence to the end. According to the WMO SPI User Guide (WMO, 2017) in defining drought duration, a drought event starts when the SPI value equals -1 and ends when the SPI value changes to positive. Based on these factors, the drought duration (DD) can be directly counted. The SPI also can readily be used to determine peak intensity shown by the lowest value of SPI on n years long of each site. The cumulative drought magnitude can be measured. Drought Magnitude (DM) is a term used to describe the severity of a drought (McKee et al., 1993) Drought magnitude is calculated by:

$$DM = -\left(\sum_{j=1}^{x} SPI_{i,j}\right) \quad (12)$$

Where DM is Drought Magnitude or Severity (months); j is the month of drought at any time scale (i) started from the first month and continues until the end of the drought happened (x).

The values of DD and DM were then used to obtain the value of Average Drought Intensity (Nosrati & Zareiee, 2011) to describe the average intensity or drought strength. ADI is calculated by dividing the value of DM by DD. The ADI measurement is essential since the DM value does not directly reflect that the region is drier than other regions. It is due to many droughts occurring in a short time but have a significant intensity of drought strength (Muharsyah & Ratri, 2015).

The next factor is to calculate the relative frequency (RF) of drought events. Relative frequency is defined as the proportion of the number of droughts that occurred (total DD value divided by the number of months) during the period analyzed (Mohseni Saravi et al., 2009; Muharsyah & Ratri, 2015). Relative frequency is formulated as:

$$F = \frac{n}{N} x100\% \quad (13)$$

Where RF is relative frequency; n is the number of months during Drought Duration that occurred, and N is the number of the total months.

Result and Discussion

Drought is a global phenomenon that occurs throughout the world, including in Indonesia. North Lombok Regency is an area that has extensive dry land, with soil types dominated by clay and clay loam of more than 60% of the site. The average monthly air temperature in this area varies between 24.20°C to 32°C where the lowest temperature occurred in February 2003, and the highest temperature occurred in October 2013. In this study, the symptoms of climate change in the North Lombok Regency were analyzed from the changes in the average monthly temperature in the first 10 years (1999-2008) and the last 10 years (2009-2018). The analysis results show that North Lombok Regency has increased in temperature by 0.20 C/year. The comparison of the 10-year average monthly air temperature is presented in Figure 2.

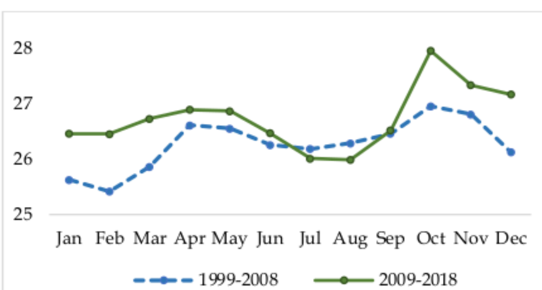

Figure 2. Average near-surface air temperature comparison

The first step of this research is to ensure data completeness. The data needed for the drought index calculation, particularly for the SPI model, must be filled in entirely without any missing data. Then, if there is any blank data, it must be interpolated using formula 1 to forecast it. In calculating the drought index using SPI, the monthly rainfall data of the site is the primary input data. The monthly rainfall data were analyzed by summarizing all daily rainfall data in a month since the data records are available in a daily format.

The rain data was then tested for consistency before being used in the subsequent analysis. The data consistency test was carried out using Rescaled Adjusted Partial Sums method, and the results showed that the data to be used is consistent.

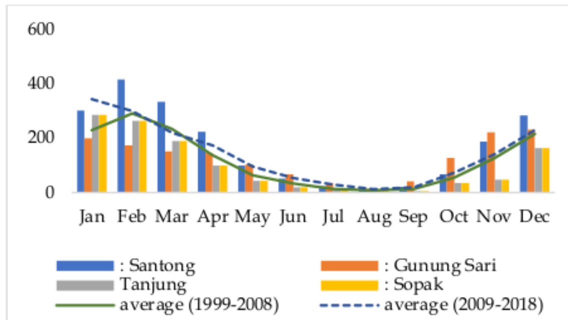

Figure 3. Averaged Monthly Rainfall in North Lombok for 1999-2018

Rainfall in the Nusa Tenggara region, especially North Lombok Regency, is included in the monsoon category (see Figure 3). Based on the data that has been collected, in the last 20 years (1999-2018), the North Lombok region has had an average annual rainfall of 1541 mm/year. High precipitation occurs at the beginning year, around January to March, and at the end of the year, around October to December. Meanwhile, mid-year rainfall tends to be low. There are many variations at the beginning of the season, both the rainy season and the dry season. And so do the beginning of the season on the island of Lombok. The rainy season is characterized by rainfall >50 mm/month, starting in October for the Santong and Gunung Sari and November and December for the Sopak and Tanjung areas.

On average, the highest monthly rainfall occurs in January, where all regions experience the highest monthly rainfall compared to other months except Santong. The highest monthly rainfall in Santong occurs in February. Besides the peak of the rainy season, which is more subsequent than in other regions, the beginning of the rainy season in Santong is also earlier than in other areas. As the topography of Santong is in a high-elevation area, it receives more orographic rain than other areas in North Lombok.

The analyses then continued by calculating the SPI drought index with 1-, 3-, and 6-month timescales. The blue line in Figure 2 depicts the SPI values of the 1-

month time scale for North Lombok Regency in the last 20 years, while the red line is an index with a value of -1, which indicates drought conditions.

The 1-month SPI drought index is inadequate to describe the incidence of drought in the site, considering the definition of drought, which represents the absence of water supply for a range (long-term) of time. So, this study applies a time scale of 3 months and 6 months in analyzing the severity of drought, intensity, and relative frequency of the drought.

The results of the calculation of the SPI index illustrate that drought occurs in almost all areas of North Lombok (see Fig 4). The results of the analysis of the SPI index demonstrate that deficiency occurs in practically all areas of North Lombok. Tanjung is the wettest area (the least experienced drought), while Gunung Sari was the driest one.

Drought can be monitored using a 3-month index or SPI3 of all available rain stations at the study site. If the SPI3 values obtained from the rain posts correspond to the occurrence of El Nino, it is believed that drought has indeed occurred. So far, it is known that El Nino plays a major role in drought in the tropics as well as in Indonesia (Mohseni Saravi et al., 2009; Muharsyah & Ratri, 2015) with a more decisive influence in areas such as western Sulawesi, parts of Maluku, Bali, and West Nusa Tenggara(As-syakur et al., 2014). The Indonesian Ministry of Environment (Boer et al., 2018) also stated that the ENSO signal is very strong in areas dominated by monsoon-patterned rainfall, such as West Nusa Tenggara Islands. Therefore, the analyzed drought factors such as the length of drought duration (DD), severity or drought magnitude (DM), average drought Intensity (ADI), and relative frequency (RF) in this study are believed to be closely related to the occurrence of El Nino.

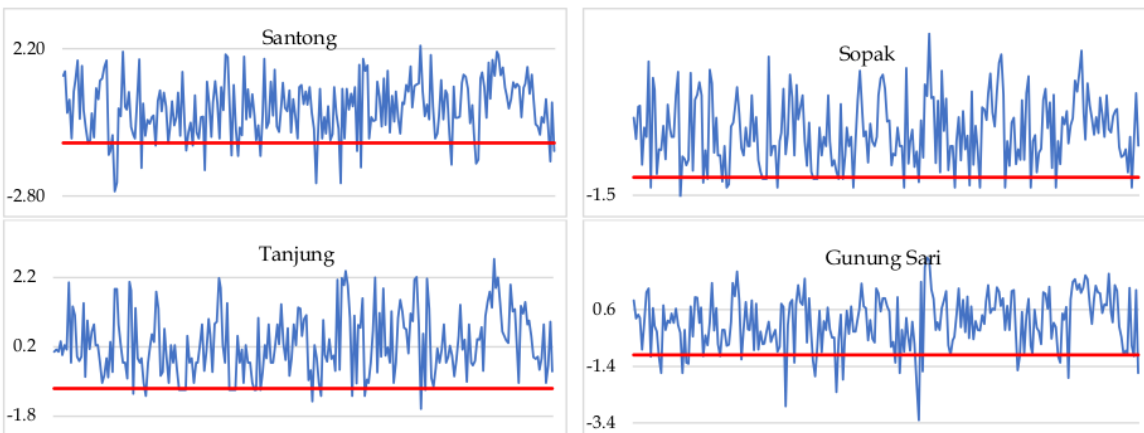

Figure 4. SPI value of 1-month time scale SPI1 for 20 years time-series for North Lombok Regency. The red line is the SPI value index of less than -1 which indicated a drought occurrence

Drought is a long-set disaster, then describing its characteristics requires an analysis based on long-duration value. In this study, the calculation of the drought characteristics DD, DM, ADI and RF were analyzed based on the SPI3 and SPI6 values. The results of the SPI3 value in North Lombok Regency during 20 years period obtained the dryness event spread throughout the North Lombok region entirely in 2001. 2001 was also the peak of the driest event where almost all of North Lombok Regency entirely had the most extensive drought index of the severely dry category. Although it happened in the same year, the drought in some different areas occurred in different months.

During this time, Santong experienced a drought from July 2020 to March 2001, Tanjung showed a drought event in July-September 2001, Sopak had a drought that started from April to September 2001, and Gunung Sari gets a drought from October 2000 to March 2001. The peak of drought with a SPI3 value of -2.605 (extremely drought category) was recorded in Santong and occurred in January-February-March (JFM) period. Meanwhile, Sopak produces the most extended drought duration index for the SPI6 value. The longest 6-month drought in Sopak was recorded from mid-2005 to the end of 2007. The second-longest 6-month drought period occurred in Gunung Sari and Tanjung, with a prolonged drought duration of up to 24 months. Meanwhile, in Santong, the 6-month drought was only recorded for 12 months.

The analyses of climate change's impact on drought characteristics were taken into 2 data groups intended to see the drought characteristics changes of the first 10-years (1999-2008) and the last 10 years (from 2009 to 2018). The result showed a significant descending trend in drought duration and intensity and drought frequency in the second period (last 10 years). Other regions also show the same direction. All areas in North Lombok experienced a decrease in all the parameter values that describe the lower value of drought measurement in the last 10 years. An overview of the decline in drought characteristics is presented in Table 3.

Table 3. The 10-year of Average Drought Characteristics of North Lombok Regency, Before and After 2008

	SPI1		SPI3		SPI6	
	1999-2008	2009-2018	1999-2008	2009-2018	1999-2008	2009-2018
Drought Duration (DD)						
Santong	0.90	0.70	2.10	0.60	2.40	0.00
Tanjung	1.05	0.40	2.70	0.00	4.20	0.00
Sopak	1.05	0.80	3.00	0.30	3.00	0.00
Gunungsari	1.00	0.95	2.10	0.30	4.20	-0.20
Drought Magnitude (DM)						
Santong	-1.49	-1.25	-0.98	-0.22	-0.50	0.00
Tanjung	-0.97	-0.50	-0.73	0.00	-0.73	0.00
Sopak	-1.28	-1.01	-1.28	-0.11	-0.64	0.00
Gunungsari	-0.88	-1.40	-0.88	-0.15	-0.78	0.60
Average Drought Intensity (ADI)						
Santong	-1.10	-1.09	-0.22	-0.04	-0.06	0.00
Tanjung	-0.43	-0.50	-0.15	0.00	-0.05	0.00
Sopak	-0.84	-1.01	-0.26	-0.04	-0.02	0.00
Gunungsari	-1.15	-1.04	-0.25	-0.05	-0.04	-0.03
Relative Frequency (RF)						
Santong	0.18	0.18	0.12	0.05	0.20	0.00
Tanjung	0.18	0.07	0.23	0.00	-0.35	0.00
Sopak	0.18	0.13	0.25	0.03	-0.25	0.00
Gunungsari	0.17	0.16	0.18	0.03	-0.35	-0.05

The SPI3 results showed that Sopak experienced a prolonged drought duration (DD) for about 3 months on average followed by Tanjung, Gunung Sari and Santong. But it has noted a prolonged drought in Tanjung as a maximum drought period of 12 months from July 2005 to June 2006. In SPI6 Tanjung and Gunung Sari averaged the same drought duration then followed by Sopak and Santong. Sopak recorded the most prolonged drought duration by 30 months of 6-month SPI on July 2005 to the end of 2007.

The magnitude of the drought depicted severity of drought was obtained by adding up the index with a value below -1 cumulatively and ends when the index shows normal conditions or reaches a positive value. In this study, the drought severity values obtained from each location were then averaged over 10 years. The results obtained provide an overview as presented in Table 3, where Santong experienced the worst drought compared to other locations with the lowest severity value of -1.49 on monthly duration of drought. Because drought events usually indicate a prolonged water shortages, this SP1 assessment usually does not reflect the actual conditions at the study site. Furthermore, an overview of drought can be obtained from SPI3 or SPI 6.

As the result of SPI3, the drought in Sopak occurred in two consecutive periods or within 6 months, while the results of the 6-month SPI showed that Sopak recorded the most prolonged drought period, which was 30 months. However, because the frequency of drought occurrence in Sopak is only one time, the average drought severity becomes lower than in other locations that recorded drought events more than once, such as Tanjung and Gunung Sari.

The intensity of drought in North Lombok described that the drought occurred in a short time but frequently has a great intensity of drought magnitude. Sopak in SPI3 has a high drought magnitude and also a high frequency. So Sopak was given a higher drought intensity compared with other regions. The value of drought duration, severity, intensity, and frequency from the SPI1, SPI3 and SPI6 on average was then tabulated in Table 4, Table 5 and Table 6.

Table 4. The SPI1 descending values of Averaged Drought Characteristics of North Lombok Regency

	Drought Duration (months)	Drought Magnitude	Drought Intensity (per month)	Relative Frequency (%)
1999-2008	1.00	-1.31	-0.88	0.17
2009-2018	0.71	-1.04	-0.91	0.13
The decrease	28.23%	23.61%	11.97%	22.68%

Table 5. The SPI3 descending values of Averaged Drought Characteristics of North Lombok Regency

	Drought Duration (months)	Drought Magnitude	Drought Intensity (per month)	Relative Frequency (%)
1999-2008	2.48	-1.03	-0.2	19.00
2009-2018	0.30	-0.12	-0.03	3.00
The decrease	86.79%	87.97%	87.27%	83.21%

Table 6. The SPI6 descending values of Averaged Drought Characteristics of North Lombok Regency

	Drought Duration (months)	Drought Magnitude	Drought Intensity (per month)	Relative Frequency (%)
1999-2008	3.45	-0.66	-0.04	28.75
2009-2018	0.15	-0.05	-0.01	1.25
The decrease	96.43%	93.43%	76.88%	96.43%

The results presented in Tables 4-6 provided an overview of a significant reduction for all drought characteristics of drought ranging from 76.88% to 96.43% for 3-monthly SPI (SPI3) and 6-monthly SPI (SPI6), and SPI1 shows a lower decreasing value of 11.97% to 28.23%. The calculation results of the SPI1, SPI3, and SPI6 are presented in Figure 5 to figure out the change in the trend direction values of the two 10-year data groups.

The average duration of drought duration in the North Lombok region shown in Fig. 5 was dominated by short-term droughts (less than 6 months). This is consistent with research on global drought spatial patterns which show the character of drought in the tropics and mid-latitudes where the various of interannual climate is highest tends to short time droughts (Sheffield & Wood, 2007).

The average drought intensity of SPI3 in North Lombok has decreased in the last 10 years by about 87.27% from the previous where the previous average value of drought intensity of -0.22 decreased to only -0.03. In average, the intensity of drought for all time scales decreased significantly by 85%. The average initial intensity of -1.44 decreased to -0.85 and the relative frequency of drought declined by about 20% from an average of 0.30 to 0.10 (See Fig.5).

The differences in drought characteristics between one region and another can be described by calculating each region's duration, magnitude, intensity, and frequency. Drought characteristics may also differ under various topographical conditions as a function of soil moisture. The drought tendency in plains and hills is greater than in highlands and mountains on all time scales (Liu et al., 2021). In addition to natural conditions such as temperature and rainfall, anthropogenic conditions in an area are also proven to be able to control and influence drought events. The anthropogenic forcing has increased the maximum of duration, intensity and frequency of drought experienced in most of Africa, Asia and Americas (Chiang et al., 2021). In order to mitigate the drought hazard in the future, the drought must be analyzed not only by its drought index but also concerning global phenomena occurrences such as El Nino.

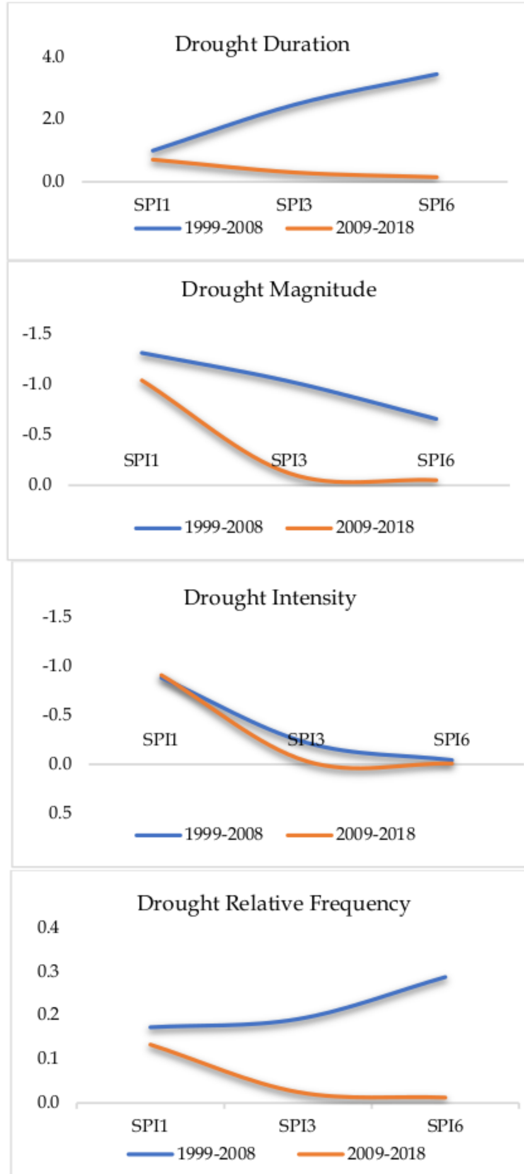

Figure 5. The 10-years drought characteristics of SPI1, SPI3 and SPI6 before and after 2008

Conclusion

The results of SPI drought index calculation (SPI3 and SPI6) using data from the last 20 years showed a significant decrease in all the characteristics, such as the duration, severity, intensity, and frequency of drought. It implies that the climate change impact on the risk of drought disaster in Lombok Island tended to decrease in the last 20 years' data. More intensive research involving more extended data is highly recommended to see better the impact of climate change on shortage in this region.

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Author Contributions
Humairo Saidah: Funding acquisition, Conceptualization, Data curation, Formal Analysis, Investigation, Resources, Software, Supervision, Methodology, Writing original draft, Writing review and editing. Lilik Hanifah: Project administration, Methodology, Validation. I Dewa Gede Jaya Negara: Resources, Software, Validation, Visualization.

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Conflicts of Interest
The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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