Analysis of drought characteristics in southern Indonesia based on return period measurement

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Abstract. The agricultural sector, especially the production of food crops is a pillar of the economy in Indonesia with production centers located in Java, Bali and Nusa Tenggara. One of the causes of the decline in food crop production is the drought caused by climate change. Drought can be calculated by the Standardized Precipitation Index which is an index to measure the severity of a region's drought. The severity of a region's drought can reach the highest value which can be used to estimate the period of drought occurring repeatedly. Furthermore, the estimation results can be used to obtain the Return Period value which is the average time of drought that has occurred by determining the maximum severity of the drought. To anticipate drought that occurs repeatedly, the purpose of this research is to identify the characteristics of drought from the Return Period based on the geographical profile of Java, Bali and Nusa Tenggara. The data used is monthly rainfall observation data for the period from 1985 to 2014 which describes the current drought events and data on monthly rainfall scenarios for the period from 2016 to 2100 based on the Representative Concentration Pathways that describe the future climate. The result of data analysis indicates that the Return Period geographically provides an overview of various regions. In the more wet region, there is a reduction in rainfall, while the drier region does not experience a significant reduction in rainfall. The general result shows, that in the long run Java will experience a reduction in rainfall more that of in Bali and Nusa Tenggara.

1. Introduction
The agricultural sector, especially the production of food crops is a pillar of the economy in Indonesia. Food crop production centers in Indonesia are in Java, Bali and Nusa Tenggara. One of the causes of the decline in food crop production is drought which results in reduced harvested area.

Drought occurs due to irregularities in normal weather conditions in an area, including reduced rainfall intensity as compared to normal conditions [1]. Drought is one of the phenomena of climate change. Climate change is one of the effects of global warming that affects the temperature of the environment. Rising sea levels, floods and droughts are examples of the result of frequent climate change. The impact of climate change felt nowadays, will increase threats to water availability, health and food availability. The impacts caused by drought can occur in various sectors of life such as economic, social and environmental. For parts of Indonesia, especially Java, Bali and Nusa Tenggara, drought is a problem faced by people almost every year.
Maps of the occurrence of drought in Indonesia between 1979 and 2009 were made by the Badan Nasional Penanggulan Bencana (BNPB). Those maps showed that the island of Bali experienced 16 incidents of drought [2]. According to BNPB in 2017, there were at least 105 regencies or cities, 715 sub-districts and 2,726 districts or villages experiencing drought in Java and Nusa Tenggara [3]. The drought that occurred on the island of Java mostly occurred in Central and West Java. West Nusa Tenggara experienced drought in 9 districts while in East Nusa Tenggara it was reported to have experienced a worse drought season. To understand the severity of dryness, a drought index is used.

Drought index used to provide quantitative values for climatic conditions through intensity, duration and severity. Drought index properties reflect various events and conditions for climate drought anomalies. There are two main objectives of the search for a drought index which are for monitoring and early warning instrument in assessing the diversity of various drought systems [4]. Using this relatively simple methodology, the drought index has developed into a detection and monitoring tool for analyzing drought levels in any region. The drought index used in general is the Standardized Precipitation Index (SPI).

SPI is an index used to determine rainfall deviations from normal over a long [5]. SPI is a probability index of rainfall data where a positive index shows wet conditions while a negative index shows dry conditions. The advantage of SPI is that it provides early warning of drought that is calculated on different time scales and can be used in monitoring agricultural as well as hydrological drought. Efforts to provide early warning can be done through an illustration of the climate in the future.

The future climate picture can describe by conducting climate projections based on certain scenarios. According to the IPCC (Intergovernmental Panel on Climate Change) [6], scenarios are not a method for predicting the future but for better understanding the uncertainty problem and an alternative picture of the future climate to answer changes from the parameters of current greenhouse gas emissions. Several climate scenarios that have been compiled by the IPCC are Representative Concentration Pathways (RCP) which is useful to determine global and regional climate projections until 2100. The IPCC Study Report uses climate modeling using RCP scenarios such as RCP 4.5 and RCP 8.5. RCP 4.5 and RCP 8.5 display data on rainfall scenarios in 2016 to 2100. Based on scenario data we can project of drought events that will occur in the future by determining at the return period.

During drought season recurring drought can be seen based on repeated drought events that are characterized by high severity. Many methods can be used to determine the occurrence of drought that will occur repeatedly, one of them called a Return Period. By utilizing observation data, RCP 4.5 and RCP 8.5 scenario data, it can be observed that drought events will repeat in 100 years using the Return Period.

2. Materials
The data used in this study were obtained from 38 stations of the Badan Meteorologi Klimatologi dan Geofisika (BMKG) which were spread in Java Island (27 stations), Bali (1 station) and Nusa Tenggara (10 stations). In this study, the data used consisted of drought data for 1985-2016 (Adhyani 2017), RCP 4.5 and RCP 8.5 scenario data for 2016-2100 (Central BMKG).

Methods
2.1. Counting return period
While scenario data was still in rainfall flux (kg/m² s⁻¹), we need to convert into monthly rainfall unit (mm/month). On the Adhyani [4] data were using monthly rainfall unit (mm/month) before they were changed into drought index calculation. After data were changed into monthly rainfall, we calculated with using SPI as an indicator of drought index.

2.2. The computation of drought index with SPI procedure.
Standardized Precipitation Index (SPI) is a method that was introduced by Tom McKee, Nolan Doesken and John Kleist in 1993 at Colorado Climate Center. They had the main objective to improve the ability of monitoring and detecting the drought in the United. According to Vicente [7], the computation in the
SPI method is relatively easier, temporary, flexible, and able to analyze the drought with only one input parameter which is precipitation. SPI can be used for determining drought level in any timescale in a rain station using historical data. SPI can also be used for determining the wet anomalous period (rain surplus). McKee classified the SPI drought index as shown in Table 1 below.

| SPI Index  | Classification         |
|------------|------------------------|
| 2.0 +      | Extremely wet          |
| 1.5 to 1.99| Very Wet               |
| 1.0 to 1.49| Moderately Wet         |
| -0.99 to 0.99| Near Normal       |
| -1.00 to -1.49| Moderately Dry   |
| -1.5 to -1.99| Severely Dry        |
| -2 and less| Extremely Dry         |

2.3. Calculation of return period
The concept of return period was introduced for the first time by Fuller (1914) who introduced the flood frequency statical analysis in United State. Return period gets widespread popularity because of its simplicity in the statical calculation which is taken in engineering practice. The drought return period can be assumed as the past average time or inter-arrival time which mean the drought occurrence with severity levels was constant or worse. Interarrival time \( L \) can be defined as the start time of drought until the other start time of another drought. The calculation of interarrival time is added between the drought duration \( L_d \) and non-drought duration \( L_b \). Shiau and Shen [8] developed the procedure to describe the return period with severity. Severity is the cumulative of SPI value in drought duration. Shiau and Shen [8] found that return period can be calculated with this equation below.

\[
E(RP) = \frac{E(L)}{1 - F_{N_S}(n_S)}
\]

2.4. Compute the return period of drought data between 1985-2014
The drought data were obtained from Adhyani [4] in dryness which has been classified with SPI index. Then, the drought data would be calculated in its return periods with the same step in scenario data.

2.5. Combined of the return period
The combined return period aimed to obtain the drought characteristic in every region that was observed. The drought characteristic that was obtained, is expected to give the drought projection in the future.

Results and Discussion
2.6. Standardized Precipitation Index (SPI)
In RCP 4.5 and RCP 8.5 scenario data, the data in the form of rainfall so that the calculation is done using the Standardized Precipitation Index (SPI) to get the drought index value. SPI can be used to determine the level of drought at various timescales (time resolution) at a rain station using historical data. Drought data results in RCP 4.5 and RCP 8.5 scenarios can be used as calculation material to obtain the Return Period. Table 2 shows the results of the drought index using SPI.
Table 2 The results of the SPI Index Wai Oti Station.

| Years | Month | SPI Index | Years | Month | SPI Index |
|-------|-------|-----------|-------|-------|-----------|
| 2016  | 1     | -0.54645  | 2016  | 7     | -0.11472  |
| 2016  | 2     | 2.21077   | 2016  | 8     | 0.74747   |
| 2016  | 3     | 1.42906   | 2016  | 9     | 0.04699   |
| 2016  | 4     | 0.06844   | 2016  | 10    | 0.14404   |
| 2016  | 5     | -0.10861  | 2016  | 11    | 0.56705   |
| 2016  | 6     | -1.74089  | 2016  | 12    | -0.70004  |

Based on the SPI index value classification [5], a dryness event is said to be dry if the index classification value is -1. In Table 3 the incidence of drought for Wai Oti Station in November 2006 with a drought index value of -1.74089 indicates drought severely, while the index 2.21077 shows extreme rainfall. The same stages are carried out for each BMKG Station used in the RCP 4.5 and RCP 8.5 scenario data from 2016 to 2100.

2.7. Cumulative Distribution Function (CDF)

Observation data, RCP 4.5 and RCP 8.5 scenario data are divided into severity forms which are then identified based on the types of data distribution. Determination of the distribution closest to the data can be shown through the statistical parameter value. Selection of distribution uses a program simulation that outputs the distribution and parameter values. Figure 1 shows the identification of the distribution in the Wai Oti Station.

![Figure 1](image_url)
Where \( \sigma \) dan \( k \) are scale and shape parameters, \( x > 0 \) for \( k \leq 0 \) and \( x \in \left[ 0, \frac{\sigma}{k} \right] \) for \( k > 0 \).

After identification the distribution is done at each station, then determine the CDF value from the data distribution obtained. The results of the CDF value will be used to obtain the Return Period.

2.8. Return Period

The drought return period can be considered as an average passing time or interarrival time which means the incidence of dryness with a fixed or greater severity [10]. Interarrival time \((L_i)\) can be defined as the period of time from the beginning of the dryness to the beginning of the next dryness by adding the duration of the dryness to the duration that is not dry.

### Table 3 Result of interarrival time in Wai Oti Station

| Period      | L  |
|-------------|----|
| Apr-Des 1986 | 8  |
| Des 1986-Jan 1988 | 13 |
| Jan 1988-Des 1989 | 23 |
| Des 1989-Mar 1991 | 15 |
| Mar-Des 1991 | 9  |
| Des 1991-Mar 1992 | 3  |
| Mar-Des 1992 | 9  |
| Des 1992-Apr 1997 | 52 |
| Apr-Nov 1997 | 7  |
| Nov 1997-Feb 2001 | 39 |
| Feb-Nov 2001 | 9  |
| Nov 2001-Feb 2005 | 39 |
| Feb 2005-Nov 2006 | 21 |
| Nov 2006-Jan 2008 | 14 |
| Jan-Apr 2008 | 3  |
| Apr 2008-Mar 2009 | 11 |
| Mar-Nov 2009 | 8  |
| Nov 2009-Feb 2010 | 3  |

In Table 2, the results of interarrival time obtained for the beginning of the drought to the beginning of the next drought at Wai Oti Station have a long interarrival in each period of drought and the highest Interarrival value occurs in the period December 1992 to April 1997 with a value of interarrival time is 52 months.

Based on drought data were calculated to get the return period to be shown in Figure 2 as follows. The three images below are taken from the same return period in the 20 years of the drought that has occurred. In Figure 2 (a) the results of the Return Period of the Curug Station drought data where drought occurs with the number of severity around 5-6 have a return period of 20 which means that drought has occurred at least 1 time in a period of 20 years.
Figure 2  Graph of Return Period for drought data (a) Curug Station, (b) Ngurah Rai Station and (c) Wai Oti Station.

In Figure 2 (b) the results of the Return Period of the Ngurah Rai Station drought data where drought occurs with severity around 6-7 have a return period of 20 and in Figure 2 (c) the return period results from the Wai Oti Station drought data where drought occurs with severity around 2-3 has a return period of 20. It means that drought has occurred at least 1 time in a period of 20 years.

Figure 3  Graph Return Period scenario data (a) Period I of RCP 4.5 (b) Period II of RCP 4.5 (c) Period III of RCP 4.5 (d) Period I of RCP 8.5 (e) Period II of RCP 8.5 and (f) Period III of RCP 8.5.
The 5th International Seminar on Sciences

RCP 4.5 and RCP 8.5 scenario data were divided into 3 periods as a projection of drought. RCP 4.5 and RCP 8.5 scenario data using the same stages as drought data stages to get results from the return period. Furthermore, the Return Period results for RCP 4.5 and RCP 8.5 are obtained with 3 periods. Figure 3 Return Period results for 3 periods for each RCP 4.5 and RCP 8.5.

2.9. Combined Return Period

Combining the Return Period results from drought data, RCP 4.5 and RCP 8.5 scenario data is done to see the projected future drought. The return period in RCP 4.5 and RCP 8.5 from 2016 to 2100 is divided into three time periods, namely near future (2016-2035), middle century (2045-2065) and end century (2081-2100) which for each time period division has a span of 20 years. The combined results of the Return Period are used to analyze the pattern of drought in each Return Period of data thickness, RCP 4.5 scenario data and RCP 8.5. The results of the combined Return Period are given in Figure 4 below.

In Figure 4(a), the Return Period results on drought data occur with the severity approaching 6 having a return period of 35 which means that there has been a drought occurrence at least once in the 35 years.

When compared to with RCP 4.5 and RCP 8.5 scenario data in the near future and middle century time periods, the pattern of drought is almost the same as the drought data with the severity of the number 4 with a return period smaller than the observation data, which is at number 25. As for the period of end century, the severity of drought events exceeds the observation rate with a faster return period of drought events.

Then in Figure 4 (b), the drought data experience a more severe drought compared to RCP 4.5 and RCP 8.5 scenario data where the return period data with a severity level 7 has a return period of 25 which means that drought occurrences occur at least once in 25 year period. When viewed between the data pattern of the middle century scenario and RCP end century 4.5 with RCP end century 8.5 Return pattern Period obtained is approaching the drought data pattern. Whereas the middle century and near
future RCP 4.5 with near future RCP 8.5 has the same Return Period period with 25 return periods which means that at least one drought will occur in the last 25 years.

Whereas in Figure 4 (c), near future pattern, middle century, RCP end century 4.5 and RCP 8.5 end century are at a severe level of drought compared to drought data where it is indicated by a pattern away from drought data with the Return Period severity between 5 with a return period of 40 which means that the occurrence of drought for each time period will occur for at least 40 years.

2.10. Drought Characteristics Based on Altitude Profile

Drought characteristics based on altitude for drought data, RCP 4.5 and RCP 8.5 scenario data in Java, Bali and Nusa Tenggara Island are divided into 3 altitude profiles, namely:

- Lowland with altitude < 200 meter
- Medium plains with altitude 200-700 meter
- Plateau with altitude > 700 meter

The results of the characteristics of drought can be shown in Figure 5 below.

Data is represented by alphabetical letters, namely A = drought data, B = near future of RCP 4.5, C = middle century of RCP 4.5, D = end century of RCP 4.5, E = near future of RCP 8.5, F = middle century of RCP 8.5, G = end century of RCP 8.5. While the altitude profile is indicated by the number, 1 = Lowland, 2 = Medium plains, and 3 = Plateau.

**Figure 5** Boxplot characteristics of drought based on altitude for (a) drought data and RCP scenario data 4.5 (b) drought data and RCP scenario data 8.5.

Based on Figure 5 (a), the scenario data for end century the maximum severity achieved increases with increasing altitude, compared to near future which has a different pattern where the middle plateau increases and returns down when increasing altitude. While Figure 5 (b), the maximum severity increases in the lowlands and goes back down for middle century and end century, compared with drought data that the maximum severity of drought increases with increasing altitude.

Based on Figure 6 (a) the maximum severity for drought data and end century moves down from the west to the east. Whereas for the near future and middle century the severity was similar in each province. Figure 6 (b) the maximum severity for drought data and end century decreases from the west to the east and for middle century the maximum severity moves up from the west to the east, but for near future the severity is similar for each province.
3. Result

Based on the result of this research can be concluded that drought projection for Java island shows that the severity of the drought is increasing, although the occurrence will be less frequent compared to the observation data. While Bali shows that the severity of drought less severe with similar return period compared to the observation data. The drought projection for Nusa Tenggara island shows that the severity of the drought that less severe with a return period often occur.

Based on the altitude profile for scenario data RCP 4.5 showed that on end century period, the maximum severity levels increased as the increasing of land height, so that on the end of the century would occur the decreasing of rainfall more. The scenario data RCP 8.5 showed that maximum severity in near future and middle century would increase on middle land and it would decrease as the increasing of land height. It means in the near future and middle century would occur the decreasing of rainfall on low lands.

Based on geographical analyze from west to east showed that end century of scenario data RCP 4.5 and RCP 8.5 showed the value of maximum severity level declined from the west to the east, so that west region would occur the decreasing of rainfall more than in the east region. Therefore, it concludes from the projection that in the long run Java Island will experience a reduction in rainfall more that of in Bali and Nusa Tenggara.

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