Comparison of suitable drought indices for Over West Nusa Tenggara

by Heri Sulistiyono

Submission date: 28-Mar-2023 03:45AM (UTC-0500)
Submission ID: 2048902781
File name: 113-review-285.docx (1.93M)
Word count: 3655
Character count: 18693

Comparison of suitable drought indices for Over West Nusa Tenggara

Humairo Saidah[1], Heri Sulistyono[2], I Dewa Gede Jaya Negara[2]

[1] Department of Civil Engineering, Mataram University, Indonesia
h.saidah@unram.ac.id

Abstract. The drought has had a significant impact on West Nusa Tenggara. Drought experienced in some areas almost every year, causing crop failure and even causing famine in 1954 and 1966. This study was conducted to find the best method for obtaining the meteorological drought index. It is essential to understand the characteristics of drought in the study area in guiding policymakers in early anticipation of this region's drought hazard. This study compares two drought index methods, SPI and PDSI, and tests their proximity to drought data in these locations. Evaluation is carried out to determine the best approach to choose for conducting a drought assessment. The best-fitted method was determined statistically by counting the number of dry months produced by the model and comparing it with the drought experienced over West Nusa Tenggara. The results obtained are the SPI method has an accuracy rate of 58% and a correlation coefficient r about 0,06. Meanwhile, the PDSI method has a better accuracy rate of 75% and a correlation coefficient r about 0.51. The PDSI method is also the most superior in accurately predicting the arrival of a dry month compared to SPI. So it can be concluded that the PDSI method is the better method for evaluating and detecting dry periods in West Nusa Tenggara.

Keywords: SPI, PDSI, drought Index.

1 Introduction

Drought is one of the phenomena that occur due to seasonal circulation under the global climate's influence, characterized by water availability far from water needs for living, agriculture, and other activities. The impact of drought events is widely recognized. Drought is directly related to public health problems, usually resulted from poor sanitation to spread disease, and can widely lead to poverty and underdevelopment of an area.

Drought is a normal phenomenon, a recurrent feature of climate variability. It differs from aridity, which is described to low rainfall regions permanently as a feature of the site climate condition. Drought is a hazard of nature in almost all climate zone types, although it varies significantly from one region to another. Drought is an abnormal period of dry weather sufficiently prolonged caused by a lack of precipitation that causes hydrological imbalance and moisture deficiency in water use requirements (McMahon, 1982)

Drought analysis is needed to support agricultural activities towards food security. Agriculture, especially rice, is the largest water consumer, which is very prone to drought. Calculation of drought analysis usually produces an index that describes the severity of the drought. Drought is classified into three categories, namely meteorological drought, agricultural drought, and hydrological drought. Meteorological drought is related to the amount of rainfall that occurs under normal conditions during a season. Agricultural dryness is associated with reduced water content in the soil (soil moisture), and hydrological dryness is related to reduced water supply from the earth.

Meteorological drought describes reduced rainfall which is the first indication of drought conditions. There are many analytical methods for detecting this meteorological drought with various advantages and disadvantages. Among the widely used methods are SPI (Standardized Precipitation Index), PDSI (Palmer Drought Severity Index), Decile Index, Theory of Run, PNI (Precipitation Normal Index), WSI (surface water supply index), and others.

This study chooses two methods, namely SPI and PDSI, to be applied in the study location. The SPI model has the advantage of being simple. It only requires rainfall data and can determine the severity of drought by measuring the rainfall deficit at various periods based on normal conditions. The SPI model was chosen because it has the advantage of being reliable, flexible, and relatively simple in calculations (McKee et al., 1993). The PDSI model is commonly used to evaluate droughts that have occurred, especially in semiarid areas and dry sub-humid climates (Quiring and Papakryiakou, 2003; Turyati 1995), where West Nusa Tenggara is a semiarid area. The PDSI model is also a standardization for all country's local climates to show relative drought or rainfall conditions (Huang et al., 2011; Suryanti, 2008). The PDSI method can also assess and predict drought (Vasiliades and Loukas, 2009).

2 Materials and Method

2.1 Study Area

The research was conducted on the two largest islands in West Nusa Tenggara Province, namely Lombok and Sumbawa islands, located at coordinates 8 ° 10 '- 9 ° 5' latitude and 115 ° 46 '- 119 ° 5' Longitude, which has a total area of around 20 164.84 km2 (Badan Pusat Statistik Provinsi Nusa Tenggara Barat, 2021). The selection of rain stations used in this study was based on two main considerations: length of data records and data completeness (minimum blank data). In the calculation, SPI uses monthly rainfall data with a fairly long data recording period as described in the WMO-No.1090 WMO SPI User Guide that the length of the data used ranges from 20-30 years, and it is better if it is more than 30 years (World Meteorological Organization, 2012).

Figure 1. West Nusa Tenggara region

2.2 Data availability

The data needed for the SPI model is rainfall, while the input data for the PDSI model is rainfall, evapotranspiration, soil type, soil structure, and land use. The primary data for this study are the monthly rainfall in the last 21 years from 1997 to 2018, which were collected from West Nusa Tenggara Regional Infrastructure Information Center. All available data used for drought index analysis, then the model's accuracy evaluation using only the indexes generated from 2012 to 2017. It is because the drought experienced data to be compared to has only been recorded since 2012.

2.3 Research Method

This study analyzed the drought index from SPI and PDSI then compared the results with experienced drought data collected from Regional Board for Disaster Management (BPBD). The month where the drought occurred will be an indexed score of -1, and when the drought not happened, it will be an indexed score of 0. The next step is to provide a drought index score calculated by the SPI and PDSI methods. In the SPI and PDSI methods' indexing system, both have almost the same range of index values, where the index value of less than -1 indicates a drought. It makes the comparison of the two methods easier because they have the same indexing class. The next step is calculating the duration of drought by accumulating drought events every month started with a score of -1 and ended when the score is 0.

The accumulated drought duration score was obtained from SPI and PDSI methods then compared to the drought scores from the BPBD data. For the same month that shows the same score, for example, both show drought or no drought, it is interpreted as suitable and given a score of 1. And if it does not match, then the score given is 0. The suitability assessment is then carried out by summed up the number of match scores. The higher the number of corresponding scores, the better the method produced a drought index

Method of completing the missing data

In some areas, the recording of rain data is sometimes incomplete. It could be due to administrative errors or recording equipment damaged. Then estimating data technique must be done to complete it. Ideally, estimating missing data carried out by comparing the data from several close stations and correlated 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 at the same time and compared it with the annual rainfall data of each station. The formula in 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: P_x = estimated value of rainfall for the ungauged station (mm); P_i = rainfall values of other rain gauges used for estimation; N_x = Normal annual rainfall data for the ungauged station; N_i = normal annual precipitation of other surrounding stations; m = number of surrounding stations

Calculating of Drought Indices

SPI computation includes of matches probability density function of the distribution of Gamma is defined by:

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

where $\alpha > 0$ is the form parameter; $\beta > 0$ is a scale parameter; and $x > 0$ is the total monthly rainfall.

$\Gamma(\alpha)$ is the Gamma function defined as: $\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1}e^{-y}dy$ (3)

The values of α and β are estimated for each rain station using the following formula :

$$\alpha = \frac{1}{4A}\left[1 + \sqrt{\left(1 + \frac{4A}{3}\right)}\right];\ \beta = \frac{\bar{x}}{\alpha};\ \text{and } A = ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad (4)$$

Where n is the amount of rainfall data.

Then calculating the cumulative chance then the Gamma spread integrated with x to give G (x):

$$G(x) = x\int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x t^{\alpha-1}e^{\frac{-x}{\beta}}dx \quad (5)$$

Then substitution of $I = \frac{x}{\beta}$, so the formula (5) becomes:

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

Since the gamma function is undefined for x = 0, the value of G (x) becomes :

$$H(x) = q + (1-q)G(x) \quad (7)$$

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

SPI value calculation:

$$Z = SPI = -\left(t - \frac{C_0 + C_1t + C_2t^2}{1 + d_1t + d_2t^2 + d_3t^3}\right);\ \text{for } 0 < \text{H(x)} \leq 0.5 \quad (8)$$

and transformation of gamma distribution: $t = \sqrt{ln\left[\frac{1}{(H(x))^2}\right]}$ (9)

$$Z = SPI = +\left(t - \frac{C_0 + C_1t + C_2t^2}{1 + d_1t + d_2t^2 + d_3t^3}\right);\ \text{for } 0.5 < \text{H(x)} \leq 1.0 \quad (10)$$

and transformation of gamma distribution: $t = \sqrt{ln\left[\frac{1}{(1-H(x))^2}\right]}$ (11)

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

Calculation of PDSI value uses the formula :

$$X = \left(\frac{z}{3}\right)_{j-1} + \Delta X;\ and\ \Delta X = \left(\frac{z}{3}\right)_{j} - 0.103\left(\frac{z}{3}\right)_{j-1} \qquad (12)$$

The index is calculated from water supply and demand computed using a complex water-balanced system based on recorded precipitation, air temperature, and the soil characteristics of the site. The calculation of potential evapotranspiration was proposed by Thornthwaite. This is required only daily averaged temperatures and latitude of the site to calculate the maximum amount of sunshine duration (Schrier et al., 2011).

The SPI and PDSI classification index describes a relative moisture condition within 9 categories, as shown in Table 1.

Table 1. The SPI and PDSI classification

SPI	Class	PDSI	Class
≥2	Extremely wet	≥ 4,00	Extremely wet
1.5 to1.99	Severely wet	3,00 to 3,99	Severely wet
1.00 to 1.49	Moderately wet	2,00 to 2,99	Moderately wet
0.5 to 0.99	Mild wet	1,00 to 1,99	Slightly wet
-0.49 to 0.49	Near normal	0,50-0,99	Incipient dry spell
-0.99 to -0.5	Mild drought	0,49- to -0,49	Slightly dry
-1.49 to -1.00	Moderately drought	-0,50 to -0,99	Moderately dry
-1.99 to -1.50	Severely drought	-1,00 to -1,99	Severely dry
≤-2.0	Extremely drought	-2,00 to -2,99	Extremely dry

The hydrologic accounting procedure of the water balance model involves the production of time series of the runoff values, recharge to the soils, moisture loss from the soils, and transpiration, as well as estimates of their potential values. From these time series, average monthly values of the potential and the actual values are calculated over the calibration interval. The coefficient of evapotranspiration a for a particular month is the quotient of an average of the actual value ET and the average of the potential value PET for that month. Similar coefficients are b, giving the ratio of average recharge to the soils R and its potential value PR, g, giving the ratio of average runoff RO and its potential value PRO,and giving the ratio of average loss of moisture from the soils L to its potential value PL. Here the overbar denotes a long-term average. Palmer's 'Climatically Appropriate For Existing Conditions' (CAFEC) precipitation

^

P is a function of the potential evapotranspiration, potential recharge, potential runoff and potential loss, weighted by their appropriate coefficients.

The SPI and PDSI classification index describes a relative moisture condition within 9 categories, as shown in Table 1.

3 Result and Discussion

3.1 Data Preparation

The first step of this research is quality data control by checking its completeness. The requirements of drought index calculation, especially for the SPI model, must be filled in completely or without any missing data during that period of use. Then if there is blank data, it needs to be interpolated to predict it using formula 1.

This study calculated SPI and PDSI index, which are divided into several regional groups. Lombok Island was divided into four regions and two regions for Sumbawa Island. First, the calculation of the regional average rainfall is calculated using the Thiessen polygon method, then it is followed by the analysis of the monthly rainfall. Monthly rainfall is the primary input data in calculating the drought index. Regional averaged monthly rainfall for each region is presented in figure 1

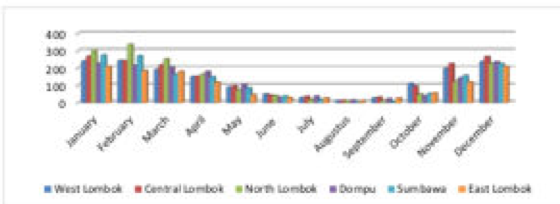

Fig. 1. Regional Averaged Monthly Rainfall over West Nusa Tenggara

Other data used in PDSI calculations are air temperature. The air temperature data is needed to calculate the potential evapotranspiration value, which is then used to determine the criteria for wet and dry months based on rainfall data and potential evapotranspiration rates. Air temperature data throughout West Nusa Tenggara is presented in Figure 2.

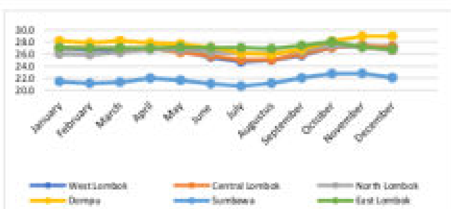

Fig 2. Averaged monthly air temperature over West Nusa Tenggara

Calculation of drought Indices

In the SPI and PDSI methods, drought occurs when the index value continuously gives a negative value and reaches a drought intensity with an index value of -1 or less. A positive index shows that the rain is greater than the median and a negative index shows that the rain is smaller than the median.

Firstly, the Indices of SPI and PDSI for any location were calculated based on the long-term precipitation record for the desired period. The SPI model is well known and becomes the most popularly used drought index (McKee et al., 1993)

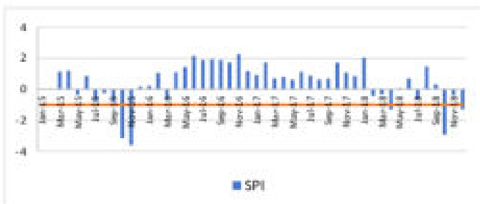

Fig 3. The example of SPI index for West Lombok. The negative value shows the strength and drought duration. The orange line indicates the start of the dry periods

The data input in the PDSI method is rainfall, groundwater capacity (WHC), and potential evapotranspiration. The advantage of this method is that in addition to producing index values, it also creates a coefficient of climate parameters, namely the evapotranspiration coefficient, the recharge coefficient, the runoff coefficient, and the moisture loss coefficient. From this coefficient, it can be calculated the rainfall that occurs during a specific month support evapotranspiration, runoff, and soil moisture reserves which are considered normal conditions. Palmer's drought index classification is divided into 11 classes with zero indexes as a normal condition. Besides, the Palmer method requires land-use data, soil type, and soil texture.

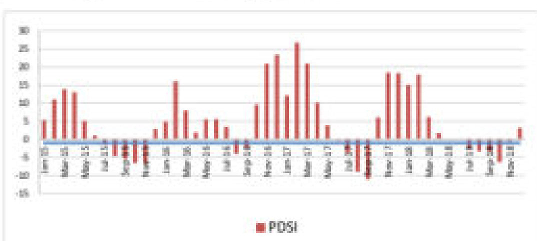

Fig 4. The example of PDSI value for West Lombok. The negative value shows the strength and drought duration. The blue line indicates the start of the dry periods

Comparison of drought index values

The accuracy test of the model evaluating the drought period is conducted by comparing the SPI and PDSI model's indices against drought data from Regional Board for Disaster Management (BPBD) West Nusa Tenggara. BPBD recorded a dry period in which the community did not have access to water, rainwater, and surface water. The month of drought recorded is an actual picture of the lack of water that occurred on site. BPBD data for deficiency are presented in numerical format, where months with drought events are given a score of -1, while months without drought are provided 0. Then it is shown in Table 2.

Table 2. West Lombok Drought experienced data

BPBD	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2014	0	0	0	0	0	0	-1	-1	-1	-1	-1	0
2015	0	0	0	0	0	0	0	0	-1	-1	-1	-1
2016	0	0	0	0	0	0	0	0	-1	-1	-1	-1
2017	0	0	0	0	0	0	0	-1	-1	-1	-1	-1
2018	0	0	0	0	0	0	0	-1	-1	-1	-1	-1

The calculation of the model's suitability is started by first giving a dumb score on the index produced from both methods. The SPI and PDSI values of < -1 are given -1 score for that means the dry period has started, and a score of 0 for the month with no drought indicated by the index values of both models are >-1. Next, check the matches of the score. Months with the same score will get a score of 1, and months with a different score will get 0. The correlation coefficients were calculated between the scores of the models and BPBD drought data (Table 4). The summary of the total match scores can then be added to find how suitable the model is. The higher the score, the higher the suitability drought index, especially in the dry month (Table 3)

Table 3. The scoring for determining of drought period and the matches of both model's score to BPDB drought score

	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Sums (2015-2018)
Score of SPI	0	0	0	0	0	0	0	0	0	-1	-1	
Score of PDSI	0	0	0	0	0	0	-1	-1	-1	-1	-1	
Score of BPBD	0	0	0	0	0	0	-1	-1	-1	-1	-1	
Score of SPI	1	1	1	1	1	1	0	0	0	1	1	32

matches to BPBD												
Score of PDSI matches to BPBD	1	1	1	1	1	1	1	1	1	1	1	37

Table 4. Correlation coefficients between SPI and PDSI to BPBD data drought period

Region	r SPI	r PDSI
West Lombok	0.282	0.512
Central Lombok	0.064	0.192
North Lombok	0.192	0.641
East Lombok	0.048	0.543
Sumbawa	-0.266	0.643
Dompu	0.076	0.529

The matches score of the drought period then summed up and calculated the matches percentage, as shown in Figure 5

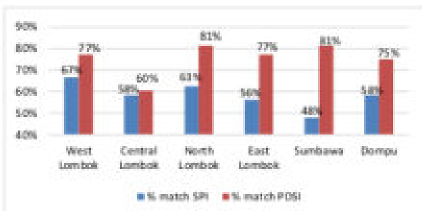

Fig 5. The matches percentage of SPI and PDSI drought period to BPBD data

Based on the calculation results presented in Figure 5, it can be concluded that the PDSI method provides a better estimation of the drought period in the study area than the SPI method. The calculation of suitability gives the result that the PDSI method has an average suitability percentage of 75% and a mean correlation coefficient (r) of 0.510, and the SPI method has an average suitability percentage of 58% and a correlation rate (r) of 0.06.

The estimation of drought duration is done by accumulating a drought index score. The more scores you get, the longer the period of the drought. A technique in accumulating drought index score started when a score shows -1 that indicates a dry period has occurred and ends at a score of 0, which means there is no more drought. The same calculation is started again when a score of -1 is found.

The cumulative score obtained will show the length of the dry month. The higher scores mean the longer the duration of the drought. The calculated drought period results in a cumulative score for 2015-2018, presented in Figure 6

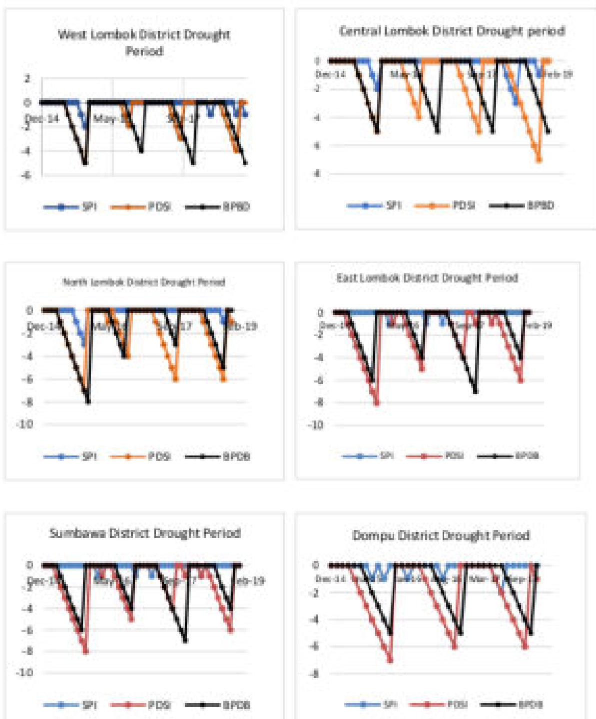

Fig 6. Cumulative score of the SPI, PDSI, and BPBD drought period

Figure 6 shows that the PDSI method appears to have a better ability to detect prolonged droughts in 2014 and 2016 than the SPI method. The SPI drought index often does not indicate drought when it occurs. On the other hand, PDSI can detect the drought that happens relatively close to the BPBD data. The calculation of accuracy is only reviewed for the presence or absence of drought, regardless of its depth and severity. So that the results of drought index calculations that show specific criteria are still ignored. Comparative data used is only the recording data of drought, which is only the drought period is compared, while the wetness period and the ranking are also ignored.

Besides requiring more data input, the PDSI method has a higher level of difficulty than the SPI method in the calculation process. So that in its application, the SPI method is still interesting to apply.

4 Conclusions

The suitability of the drought indices calculating techniques compared to experienced drought data, the PDSI method can evaluate and determine the drought period properly for West Nusa Tenggara. The PDSI method gave an accuracy rate of 75% for dry months tested conditions while SPI only 58%. The correlation number of indexes correlated with drought occurrence is about 0.51 for PDSI and 0.06 for SPI..

References

Commented [u1]: add up to 20 references with the last 5 year issue

1. Adhyani, N.L., June, T., Sopaheluwakan, A., 2017. Exposure to Drought: Duration, Severity and Intensity (Java, Bali and Nusa Tenggara). IOP Conf. Ser.: Earth Environ. Sci. 58, 012040. https://doi.org/10.1088/1755-1315/58/1/012040
2. Badan Pusat Statistik Provinsi Nusa Tenggara Barat, 2021. Luas Daerah Nusa Tenggara Barat 2015-2017 [WWW Document]. URL https://ntb.bps.go.id/indicator/153/56/1/luas-daerah-nusa-tenggara-barat.html (accessed 3.30.21).
3. De Silva, R.P., Dayawansa, N.D.K., Ratnasiri, M.D., 2007. A COMPARISON OF METHODS USED IN ESTIMATING MISSING RAINFALL DATA. The Journal of Agricultural Sciences 3, 101–108.
4. Huang, S. Dahal, D. Young, C. Chander, G. dan Liu, S. 2011. *Integration of Palmer Drought Severity Index and Remote Sensing Data to Simulate Wetland Water Surface from 1910 to 2009 in Cottonwood Lake Area*. North Dakota. Remote Sensing of Environment. Vol. 115, hal. 3377-3389
5. McKee, T.B., Doesken, N.J., Kleist, J., 1993. THE RELATIONSHIP OF DROUGHT FREQUENCY AND DURATION TO TIME SCALES 6.
6. McMahon, T., 1982. Arenas A D. Methods of computation flows. Gustard 107.
7. McKee, T. B. N. J. Doesken and J. Kleist. 1993. *The relationship of drought frequency and duration of time scales*. Eighth Conference on Applied Climatology. American Meteorological Society. Jan17-23. Anaheim CA. pp.179-186
8. Quiring, S.M. dan Papakryiakou, T.N. 2003. *An Evaluation of Agricultural Drought Indices for the Canadian Prairies*. Agricultural and Forest Meteorology. Vol. 118, hal 49-62.
9. Suryanti, Ika. 2008. *Analisis Hubungan Antara Sebaran Kekeringan Menggunakan Indeks Palmer Dengan Karakteristik Kekeringan*. Skripsi. Bogor: IPB

10. Schrier, G. van der, Jones, P.D., Briffa, K.R., 2011. The sensitivity of the PDSI to the Thornthwaite and Penman-Monteith parameterizations for potential evapotranspiration. Journal of Geophysical Research: Atmospheres 116. https://doi.org/10.1029/2010JD015001
11. Turyanti, A. 1995. *Sebaran Indeks Kekeringan Wilayah Jawa Barat*. Skripsi. Jurusan Geofisika dan Meteorologi. FMIPA IPB
12. Vasiliades, L. dan Loukas, A. 2009. *Hydrological Response to Meteorological Drought Using the Palmer Drought Indices in Thessaly*. Greece. Desalination. Vol. 237. hal. 3-21.
13. World Meteorological Organization, 2012. Standardized precipitation index user guide.

Commented [u2]: not cited in the script…

Comparison of suitable drought indices for Over West Nusa Tenggara

ORIGINALITY REPORT

19%	19%	6%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

MATCH ALL SOURCES (ONLY SELECTED SOURCE PRINTED)

7%

★ sipil.ft.uns.ac.id

Internet Source

Exclude quotes	On	Exclude matches	< 3%
Exclude bibliography	On		

Comparison of suitable drought indices for Over West Nusa Tenggara

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12