

# THE CAUSALITY RELATIONSHIP OF EL NIÑO SOUTHERN OSCILLATION (ENSO) AND INDIAN OCEAN DIPOLE (IOD) ON METEOROLOGICAL DROUGHT IN BALI

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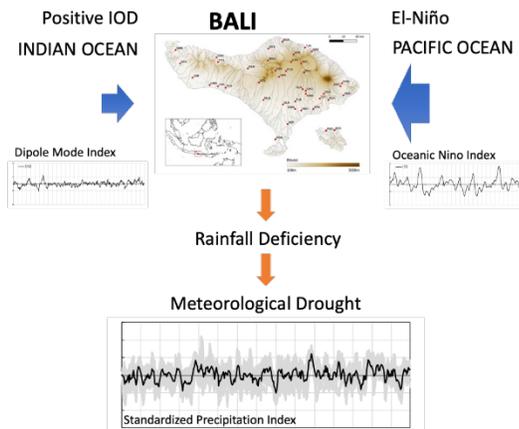
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## Graphical abstract



## Abstract

Drought is a slow-onset disaster with far-reaching impacts. Drought often begins with a deficiency in precipitation, which is called meteorological drought, caused by fluctuations in atmospheric responses to the biosphere. El Niño, a temperature anomaly in the Pacific Ocean, leads to longer dry season in Indonesia, particularly the eastern region. Meanwhile, temperature anomalies in the Indian Ocean, known as positive Indian Ocean Dipole (IOD), induce dry condition in western Indonesia. This study aims to evaluate the influence of the El Niño phenomenon and positive IOD on drought occurrences in Bali, a region situated in the middle part of Indonesia. Monthly precipitation data is collected from a total of 43 rain stations throughout Bali. The Standardized Precipitation Index (SPI-3) on a 3-month time scale is used to quantify dryness level. SPI-3 is linked to the Ocean Niño Index (ONI) and Dipole Mode Index (DMI) using Pearson's correlation coefficient and Linear Granger causality test. The findings of this study show that the correlation between SPI and ONI is stronger than the correlation between SPI and DMI. The drought resulting from the concurrent occurrence of El Niño and Positive IOD was more severe compared to drought caused solely by El Niño. Both El Niño and Positive IOD did happened together in 1997 and 2006-2007 caused the SPI3 value more negative than 2015 and 2019 which El Niño and Positive IOD happened solely respectively.

**Keywords:** Climate variability, drought, causality test, sea surface temperature, standardized precipitation index

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## 1.0 INTRODUCTION

In general, the definition of drought is water deficiency [1]. The context of the water deficiency is based on each stage of the water cycle. For example, a deficiency in precipitation is referred as a meteorological drought, a deficiency in soil water content is referred as a soil moisture drought or agricultural drought, and a deficiency in surface stream flow and/or groundwater flow is referred to as a hydrological drought [2]. Deficiencies at each stage of the water cycle can continue to affect socio-economic aspects which are referred to as socio-economic drought [3].

Given the nature of drought is a creeping disaster as it happens slowly from each water cycle stage, making its domino effect to the point of no return [1]. Although the initial stage of drought begins with a precipitation deficiency, the precipitation deficiency referred here is not always a period without rainfall, instead is a period where rainfall at certain time periods is lower than at overall period [4]. This differentiates drought as a disaster from aridity where low precipitation is a normal condition [2].

Indonesia, as a tropical region, does not free from drought disasters [5,6]. According to disaster data record from Indonesia

National Disaster Agency (BNPB), more than 2000 drought events in the agricultural sector and raw water requirements were recorded from 1991 to 2020. In those periods, a total of 1.2 million hectares of agricultural area experienced crop failure and a total of 17.3 million people had to be evacuated to secured source of water, especially on Indonesia rural area. Most of these records are in line with rainfall deficiency conditions that occur based on data from the Indonesia Meteorology, Climatology and Geophysics Agency (BMKG). This alignment is a form of meteorological drought propagation. Meteorological drought in Indonesia is generally caused by the phenomenon of climatological interaction between the atmosphere and the oceans around Indonesia. This interaction usually becomes an anomaly that occurs repeatedly irregularly. Some of these anomalies are El Niño–Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) [8].

ENSO is an anomalous phenomenon that occurs in the Pacific Ocean, while IOD occurs in the Indian Ocean. The anomaly that occurs is a change in sea surface temperature, either warming (El Niño and Positive IOD) or cooling (La Niña and Negative IOD) which causes a change in the direction of the wind that carries clouds [9]. Theoretically, the wind will move from cold to warmer temperatures in some form of a cycle. When El Niño and Positive IOD occur, rain-bearing clouds tend to move towards each ocean. This then causes a decrease in rainfall in Indonesia. The level of influence between ENSO and IOD is based on the distance of a location in Indonesia to one of the oceans. Several studies have found that ENSO tends to affect eastern Indonesia [10,11] and IOD affects western Indonesia [12,13]. ENSO and IOD are usually monitored together with index values for sea surface temperature fluctuations that occur, namely the Oceanic Niño Index (ONI) for ENSO and the Dipole Mode Index (DMI) for IOD. Each index is provided by the National Oceanic and Atmospheric Administration (NOAA) and freely accessible on NOAA website since 2005 for index database from 1950 (ONI) and 1870 (DMI).

Bali is one of the provinces located in middle Indonesia zone. As a land that is fairly known for its tourism around the world, the demand for water is relatively high. However, Bali is one of the regions that is in the category of vulnerable to meteorological drought [14]. Based on BNPB data, more than 200 drought events have been reported from 1991 to 2020. The most severe drought happened in 1997, 2006–2007, 2015 and 2019 which affected more than 2100 hectares crop areas and 50,000 people had to evacuate to secure water sources. Precisely in those years, ONI and DMI value is also recorded to be either El Niño or Positive IOD or both happened at same time on moderate to extreme scale. Some studies suggest that anomaly in the ocean propagate to some extreme rain and no rain (drought) events [15,16]. High ONI and DMI value on some of meteorological drought record in Bali also one of potential that these events have causality relationship to Bali meteorological drought.

In climate and environmental problems, causality analysis has become one of popular research focus [17]. Understanding the causality relationship is important to mitigate and plan effective solutions, as the complexity of various variables in climate and environmental problems is getting more attention [18]. There are some example studies looking into meteorological drought conditions in Bali [14,19]. However, none of them consider the potential of causality relationship from both ENSO and IOD. Understanding causality relationship

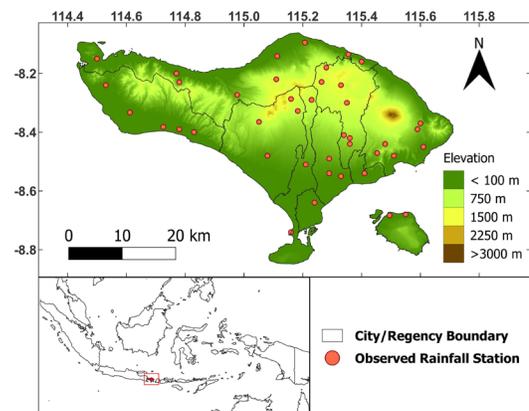
between ENSO and IOD to meteorological drought in Bali is important to further mitigate drought disaster in Bali by knowing which phenomenon is more frequent affecting it. This research aims to prove the causal relationship between the El Niño and Positive IOD phenomena on meteorological drought in Bali using statistical analysis method by Granger [20]. Furthermore, to prove the causality analysis, temporal-spatial is also done by observing the developments pattern of meteorological drought affected area in some of periods that have extreme value.

## 2.0 METHODOLOGY

In order to identify the influences of ENSO and IOD phenomenon to meteorological drought in Bali, several steps of analysis need to be taken. First is to analyze association between ENSO and IOD with meteorological drought using correlation analysis, and second is verify whether those associations are causality relationship with spatial analysis. In this study, ENSO and IOD relationship to meteorological drought is assumed linear as the causality test used is Linear Granger causality test.

### 2.1 Study area and data

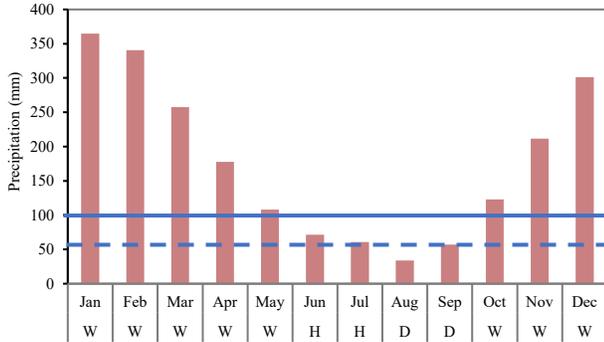
This study focused on Bali Province which consists of Bali Island that has an area of 5636.6 km<sup>2</sup> and Penida Island that has an area of 202.8 km<sup>2</sup>. Bali is located at middle Indonesia zone at latitude of 8°3'38" S – 8°50'56" S and longitude 114°25'53" E – 115°42'39" E. This study uses monthly observed precipitation data from 43 observed rainfall station provided by Indonesian Meteorology, Climatology and Geophysics Agency (BMKG) and Bali River Basin Management Agency from 1991 to 2020. The location of observed rainfall station and rainfall station shown in Figure 1.



**Figure 1** Study area consists of Bali Island and Penida Island with observed rainfall station location (Base map: Geospatial Agency of Indonesia)

Annual precipitation in Bali is around 1900 to 2200 mm/year, while the Indonesia average annual rainfall is around 2700 mm/year based on BMKG data. Figure 2 shows fluctuations graph of monthly precipitation average in Bali from 1991 to 2020 of 41 rainfall stations. The classification in Figure 2 is based on Schmidt, et al. [21] of monthly precipitation (P) value. Based on the graph, it can be identified that dry season (precipitation

less than 100 mm/month) in Bali is starting from June until September and rainfall season is starting from October until May. Monthly precipitation data is used to evaluate drought conditions using drought indices, and minimum 30 years data length is used based on World Meteorological Organization (WMO) handbook of drought indicators and indices [22]. Drought indices are then compared to climatic indices for ENSO and IOD phenomenon to identify its relationship.



**Figure 2** Monthly average precipitation category of wet (W) for  $P \geq 100$  mm (solid line), humid (H) for  $100 \text{ mm} < P < 60 \text{ mm}$ , and dry (D) for  $P \leq 60 \text{ mm}$  (dash line) in Bali.

The predominant technique for monitoring the ENSO and IOD phenomena involves detecting fluctuations in sea surface temperatures. [23,24]. Oceanic Niño Index (ONI) and Dipole Mode Index (DMI) is NOAA's primary indicator for monitoring seasonal climate patterns in Pacific Ocean and Indian Ocean. Both tracks the 3-month running average sea surface temperature in certain area in Indian and Pacific Ocean whether they are warmer or cooler than average. DMI represents anomalous sea surface temperature gradient between western and southeastern equatorial Indian Ocean, while ONI represents east-central tropical Pacific Ocean. Although both indices are generally monitored using the same method, ONI and DMI have different value thresholds to determine shifting in each cycle. ONI has threshold value of  $\pm 0.5^\circ\text{C}$  while DMI is  $\pm 0.4^\circ\text{C}$ , based on NOAA's user guide. The difference in threshold is mostly because of the size of the ocean to be resulting anomalies after effect like a storm vortex. In this study, the period data for ONI and DMI used are from 1991 to 2020, same as periods of monthly precipitation data.

## 2.2 Meteorological Drought Indices

There are over 20 meteorological drought indices that have been developed based on WMO handbook [22]. The number of existing indices is in line with developments of understanding the meteorological drought phenomenon. The most popular and widely used to calculate meteorological drought is Standardized precipitation index (SPI) by Mckee et al. [4]. These are because of simplicity in their calculation and being of multi-scalar [6,25]. SPI calculated using only monthly precipitation data and could approach of  $n$ -scale month of precipitation to probability distribution function. SPI formula is developed based on modified gamma distribution  $H(x)$  by Abramowitz et al. (1965) [26] of probability zero with the coefficient of random normal variable  $Z$  value. SPI formula is described in Equation (1) to (3).

$$Z = SPI = \pm \left( t - \frac{c_0 + c_1 t + c_2 t}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad (1)$$

$$t = \left( \ln \frac{1}{(u - H(x))^2} \right)^{1/2} \quad (2)$$

$$H(x) = q + (1 - q)G(x) \quad (3)$$

where  $G(x)$  is gamma distribution of  $x$  (precipitation) of  $n$ -scale months,  $q$  is probability of zero value in monthly precipitation, and the  $Z$  coefficient is:  $c_0 = 2.515517$ ;  $c_1 = 0.802853$ ;  $c_2 = 0.010328$ ;  $d_1 = 1.432788$ ;  $d_2 = 0.189269$ ;  $d_3 = 0.001308$ . To normalize the modified gamma distribution  $H(x)$ , the  $Z$  value in Equation (1) is calculated as positive equation if  $0.5 < H(x) \leq 1.0$  and  $u$  in Equation (2) is a constant with value equals 1. Furthermore, if  $0 < H(x) \leq 0.5$  then  $Z$  value calculated as negative, and  $u$  is 0. The SPI values that have been obtained are then categorized into: Extreme drought ( $SPI \leq -2$ ), severe drought ( $-1.99 \leq SPI \leq -1.50$ ), moderate drought ( $-1.49 \leq SPI < -1.00$ ), normal ( $-1.00 \leq SPI \leq 1.00$ ), moderate wet ( $1.00 < SPI < 1.50$ ), humid or severe wet ( $1.50 \leq SPI \leq 1.99$ ), and extreme wet ( $SPI \geq 2.00$ ).

In this study, 3-month standardized precipitation index (SPI3) is used as indices of wet/drought conditions. The use of 3-month SPI scale is suggested to be the effective scale in relation to meteorological-climatological drought impact [27].

## 2.3 Pearson Correlation Coefficient (PCC)

PCC is a method that has been widely used to measure linear relationship between two data sets [28]. This study uses PCC value to measure the level of relationship between ENSO and ONI with meteorological drought in Bali. The method is to calculate the PCC ( $r$ ) value of ONI-SPI3 to measure the level of relationship ENSO and meteorological drought, and so for IOD with PCC ( $r$ ) value of DMI-SPI3. PCC is determined on each rainfall station and then spatially mapped to know which region in Bali has greater effects of either ENSO or IOD. PCC is calculated by Equations (4):

$$r_{A,B} = \frac{S_{A,B}}{S_A \cdot S_B} \quad (4)$$

where  $S_{A,B}$  is covariance of variable  $A$  and  $B$ ,  $S_A$  and  $S_B$  is standard deviation of variable  $A$  and  $B$  respectively. The PCC ( $r$ ) value from Equation (4) then categorized as: no correlation ( $r < 0.1$ ), weak correlation ( $0.1 \leq r < 0.25$ ), moderate correlation ( $0.25 \leq r < 0.5$ ), strong correlation ( $0.5 \leq r < 0.75$ ) and very strong correlation ( $0.75 \leq r \leq 1$ ).

## 2.4 Linear Granger Causality Test (LGCT)

LGCT is a statistical test to identify possible causal relationships between variables. LGCT originally proposed as a method to predict economic data time series by Granger [20]. The linear correlations analysis method suffered from the issue of being symmetric issue and didn't provide direction of the relationship between variables. On the other hand, Granger causality is able to map the predictive of other variables and therefore is not symmetrical. The concept of Granger causality is "a variable  $Y$  is causal for another variable  $X$  if information of the past history of

$Y$  is useful for predicting the future condition of  $X$  over and above information of the past history of  $X$  itself". Thus, if the prediction of  $X$  is improved by including  $Y$  as a predictor, then  $Y$  is said to be Granger causal for  $X$ . Granger causality models have been shown to be effective to identified relationships in climate and environmental systems [29].

The causal model of two stationary variables of time series data  $X_t$  and  $Y_t$  was established using Equation (5) and (6):

$$X_t = \sum_{j=1}^{m_1} a_j X_{t-j} + \varepsilon_t \quad (5)$$

$$X'_t = \sum_{j=1}^{m_1} a_j X_{t-j} + \sum_{i=1}^{m_2} b_i Y_{t-i} + \varepsilon'_t \quad (6)$$

where  $X$  is SPI3 time series,  $Y$  is climate index (ONI or DMI),  $t$  is the length of time series,  $a$  and  $b$  are regression coefficients, while  $\varepsilon_t$  and  $\varepsilon'_t$  are error terms. Equation (5) is restricted autoregressive model of variable  $X$  which utilizes past  $m_1$  values of  $X$  to predict value of  $X$  at the time  $t$ . Equation (6) is unrestricted model that also includes past  $m_2$  values of  $Y$  while predicting the value  $X$  at time  $t$ ,  $m_1$  and  $m_2$  represent the optimal lag time for  $X$  and  $Y$ .

To test whether unrestricted estimates were able to provide more variance in the data than restricted estimates and both are significantly different, a statistical  $F$ -test is used. The  $F$ -test value obtained using Equation (7):

$$F = \frac{(SSR - SSR')/m_2}{SSR'/(n - m_1 - m_2 - 1)} \quad (7)$$

where  $SSR$  and  $SSR'$  are the sum of squared residuals for restricted and unrestricted models respectively,  $n$  is the size of the simulated vector. The null hypothesis ( $H_0$ ) is  $Y$  does not cause  $X$  and the alternative hypothesis ( $H_1$ ) is  $Y$  is causing  $X$ . Furthermore, the null hypothesis of the non-causality is identified by significance value level of  $p$  provided under the computed  $F$ -value in Equation (7). The larger  $F$ -value and the lower  $p$ -value indicate the maximum causality.

It is important to choose optimum lag length for Granger causality test as it will affect the results. In this study, 1 month lag time is used based on the research results by Sun et al. [29] in the consideration of optimum lag order of SPI and southern oscillation index (SOI) and Niño 3.4 index. LGCT is done on each rainfall station data, and the  $p$ -value is also spatially mapped to identify possible causality relationship between SPI3 with ONI and DMI. We also use the term "Granger cause" of limitations in LGCT, that is assessing predictive power of past information from  $X$  to future  $Y$  statistically and does not fully guarantee causality relationship as there might be many factors to be considered.

## 2.5 Spatial Distribution Analysis

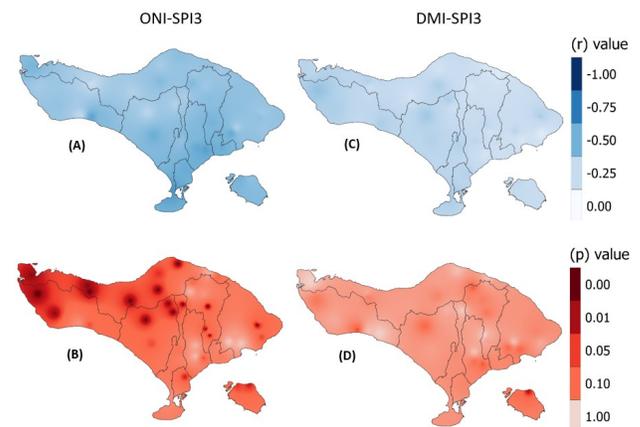
Each ONI-SPI3 and DMI-SPI of PCC ( $r$ ) value and LGCT ( $p$ ) value are spatially analyzed using inverse distance weighting (IDW) method. IDW is the most popular spatial interpolation method used to map the effects of drought severity because of its efficiency. The accuracy of IDW method of the area affected by drought is also comparable to other interpolation methods. In this study, spatial resolution of 0.085x0.085 pixel is used in IDW

analysis with QGIS. The map results from spatial analysis are used to identify the level of ONI and DMI with SPI3 relationship throughout Bali. Moreover, to verify the level of relationship for each ONI and DMI to SPI3, the development of spatial distribution of SPI3 is also conducted at extreme periods of ONI and DMI.

## 3.0 RESULTS AND DISCUSSION

### 3.1 ONI/DMI and SPI3 Relationship

Figure 3 shows the relationship between SPI3 and the climate indices (ONI and DMI) throughout Bali. The PCC ( $r$ ) value and LGCT ( $p$ ) value on each rainfall station were spatially interpolated using inverse distance weighting (IDW) method.



**Figure 3** Bali maps of the PCC ( $r$ ) value and LGCT ( $p$ ) value for SPI3 with DMI and ONI  
(Base map: Geospatial Agency of Indonesia)

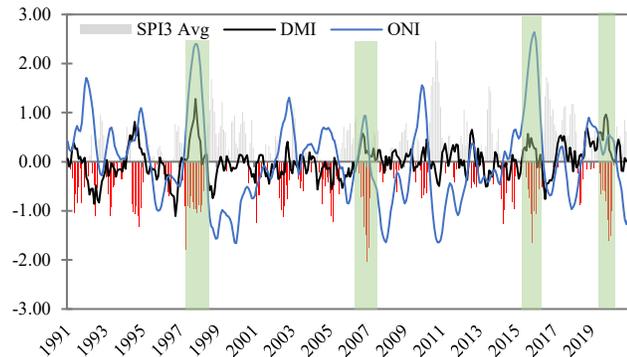
The ONI-SPI has PCC ( $r$ ) value in the range -0.5 to -0.25 as shown in spatial gradation Figure 3A, while the PCC ( $r$ ) value of an average SPI3 (SPI3 Avg) all station combined is -0.42. Furthermore, Figure 3B shows interpolated map of LGCT ( $p$ ) value of ONI-SPI from each rainfall station in range 0.05 to 0.01 which mean ONI is indeed Granger cause SPI3 in significance of 95% to 99% confidence level. The spatial IDW interpolation might have some bias because of the threshold value used. Overall LGCT ( $p$ ) value of SPI3 average from all stations to ONI is 0.022 which rejects null hypothesis in 95% confidence level. Moreover, 20 of 41 rainfall stations reject null hypothesis with the same 95% confidence level, and up to 24 rainfall stations reject null hypothesis with 90% confidence level. Rainfall stations in the western area Bali even have LGCT ( $p$ ) value near 0 which means great significance of ONI is Granger cause SPI3, although there are also some areas that have LGCT ( $p$ ) value more than 0.1 which completely accept the null hypothesis. In conclusion, these results show that ENSO phenomenon have great correlation and a Granger cause Bali meteorological drought.

On the other hand, DMI-SPI3 relationship shows PCC ( $r$ ) value of an average SPI3 (SPI3 Avg) all station combined with DMI is -0.20 which categorized as weak correlation based on Table 1. Furthermore, as shown in Figure 3C, the spatial gradation of PCC ( $r$ ) value is mostly in the range -0.10 to -0.25, Although some of areas show value near zero, it does not mean DMI has no correlation at all to SPI3. The LGCT ( $p$ ) value of an average SPI3 all station with DMI is -0.24 which accepts the null

hypothesis of there is no linear Granger causality relationship. However, the LGCT (p) value from each station shows that there is still a causality relationship between DMI and SPI3, though it is a weak causality with confidence level used is 90%. 5 of 41 rainfall stations are able to reject null hypothesis with 90% confidence level. The gradation range of interpolated (p) values in Figure 3D is more than 0.1 in most areas of Bali. Similarly, as PCC (r) distribution before, these results do not mean that there is no actual causality relationship between meteorological drought with IOD in Bali, it just shows that from both PCC (r) value and LGCT (p) value IOD is less affecting meteorological drought in Bali.

**3.2 Drought Development In Extreme Years**

Further analysis of causality relationships between ONI/DMI and meteorological drought (SPI3) in Bali is done by observing spatial developments of drought affected areas of extreme time periods ONI, DMI and SPI3. Figure 4 shows the comparison graph of SPI3, ONI and DMI values. The relationship between ONI or DMI with SPI3 is a reverse correlation which means that whether ONI/DMI gets higher, the SPI3 gets lower. Total 4 years of extreme ONI/DMI and SPI3 value of reversed graph were chosen, that is 1997, 2006-2007, 2015 and 2019. Precisely, based on BNPB and BMKG data, the years of 1997, 2006-2007, 2015 and 2019 were the year that recorded of actual drought disaster in various cities and regency in Bali affecting crop areas, tap water supply, etc.

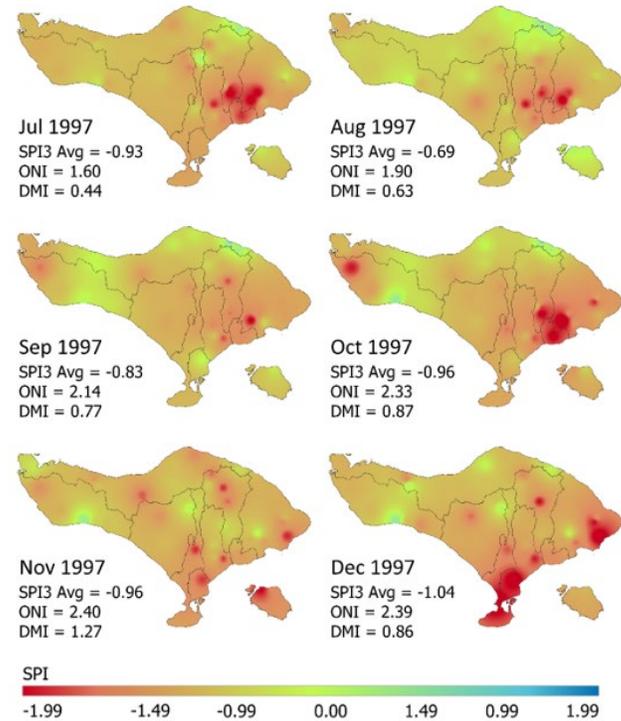


**Figure 4** SPI3 with ONI-DMI comparison graph. The year with the most SPI3≤-1 is: 1997, 2006/2007, 2015 and 2019.

In 1997, the critical month of SPI3's lowest value, happened in May 1997. However, the critical month of ONI/DMI values happened in October to December 1997 as shown in Figure 4. It is unclear the reason behind the sudden drop in SPI3 value in May 1997 as neither ONI nor DMI value is at its peak value. Figure 5 also shows that the drought affected area from Jul to December 1997 is starting at eastern Bali which is closer to Pacific Ocean as ONI value rises. These developments support that in 1997 ENSO is relatively more causing meteorological drought from SPI3 value rather than IOD [14]. Even with DMI value is relatively extreme above 1.00 value in November 1997, there is no sign that it is after effecting meteorological drought in Bali from SPI3 value developments in these periods.

The lowest SPI3 Avg value for periods 1991-2020 is in January 2007 as shown in Figure 4 and Figure 6. In these periods of 2006-2007 the drop in SPI3 value is in line with a rise in ONI and DMI values. As ONI value peaked in both November-December 2006

with value 0.94 and DMI peaked in November 2006 with value 0.5, the SPI3 drop value in January 2007 indicates aftereffects of El Niño and Positive IOD. Although the value of ONI and DMI in these periods were not as high as in 1997, these become one of supporting findings that interactions of both El Niño and IOD Positive altogether is increase severity of meteorological drought. However, the most dominant anomaly affecting meteorological drought in these periods is El Niño. These shown from the developments of area affected are starting from eastern Bali in November 2006 spreading to all over Bali in January 2007.



**Figure 5** Temporal-spatial development of SPI3 values in 1997. (Base map: Geospatial Agency of Indonesia)

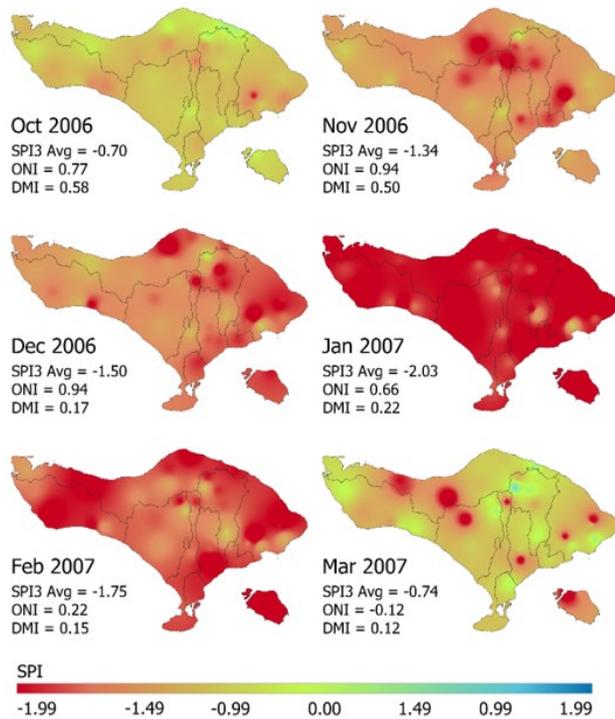


Figure 6 Temporal-spatial development of SPI3 value from Oct 2006 to Mar 2007 (Base map: Geospatial Agency of Indonesia)

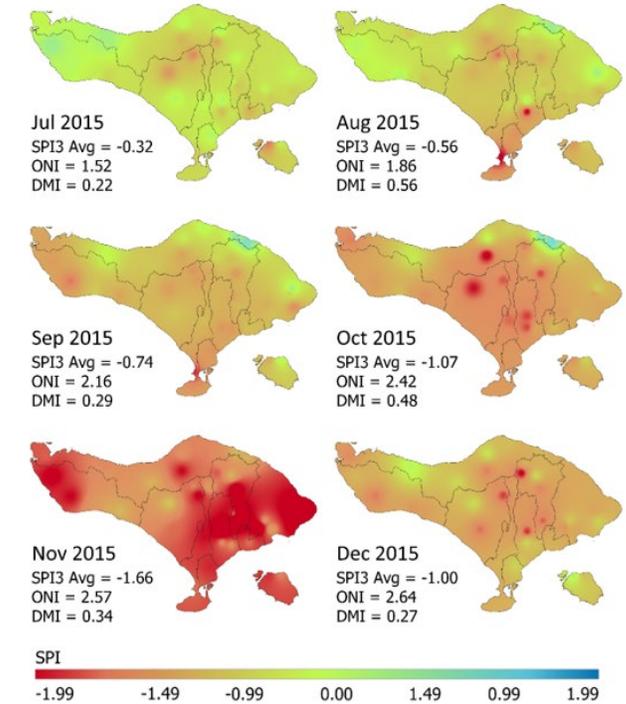


Figure 7 Temporal-spatial development of SPI3 values in 2015 (Base map: Geospatial Agency of Indonesia)

Another good example of El Niño influences for meteorological drought is in 2015 as shown in Figure 7. Eastern Bali keeps showing the same pattern as the starting point of drought affected area developments in line with ONI value rise. This was the same as 1997 and 2006-2007 before, but the development shown in 2015 is the better. As eastern Bali SPI3 value got lower spreading to southern Bali, the ONI value is also increasing simultaneously and both peak values happened at the same time in December 2015. On the other hand, DMI value relatively in neutral phase threshold, only in August and October 2015 it reached beyond the Positive IOD threshold of 0.4. These findings show that ONI solely could affect meteorological conditions in Bali, and it is relatively severe, with 20 of 41 rainfall stations categorized as extreme drought in December 2015.

As for the IOD phenomenon, we found that in the year 2019 IOD has influences of meteorological drought Bali as shown in Figure 8. The pattern shown in Figure 8 shows a potential 1-month lag time, as the DMI value rose to highest value starting in September 2019, and the SPI3 value gets lower starting in October 2019. In those periods ONI has relatively low value and only in November and December 2019 that it exceeds the 0.5 threshold of El Niño cycle shifting. The influence of mostly IOD phenomenon also supported by the starting point of the drought in this period was from western Bali which closer to Indian Ocean and spreading to southern Bali. These developments indicate strong influence of IOD phenomenon to meteorological drought in Bali in 2019. The most severe drought happened in this period is in December 2019 with 22 of 41 stations having SPI3 value on extreme drought category.

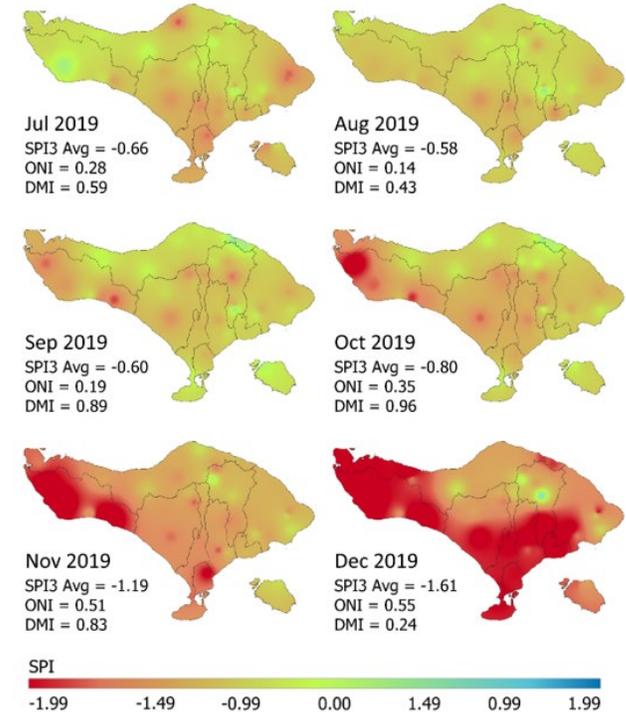
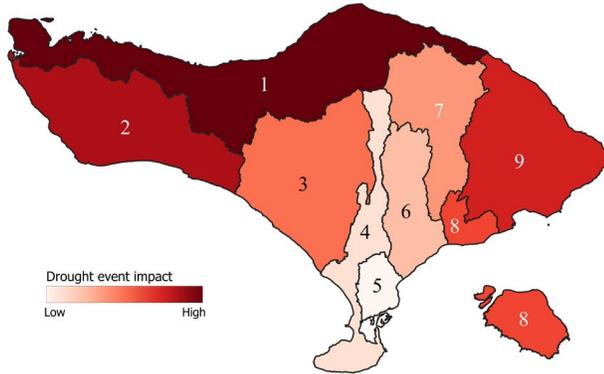


Figure 8 Temporal-spatial developments of SPI3 values in 2019 (Base map: Geospatial Agency of Indonesia)

### 3.3 Drought-Prone Area Identification

The identification of drought-prone area is done by comparing the PCC (r) value, LGCT (p) value and number of SPI3 value  $\leq -1$  each station with the BNPB drought impact events record (tap

water supply, crop failure, etc.) from 1991-2020 as shown in Table 1 with Figure 9 as regency/city border information.



**Figure 9** drought impact event record 1991-2020 within regency/city. (Base map: Geospatial Agency of Indonesia)

**Table 1** BNPB drought impact event record 1991-2020 within regency/city in Bali. (source: Indonesia Disaster Information Database).

No	Regency/City	Frequency of reported drought impacts (1991-2020)	Average Frequency of SPI3 $\leq -1$ (1991-2020)
1	Buleleng	2088	46
2	Jembrana	1939	44
3	Tabanan	756	40
4	Badung	432	32
5	Denpasar	324	30
6	Gianyar	461	41
7	Bangli	647	34
8	Klungkung	1184	36
9	Karang Asem	1548	37

Western Bali that consists of Buleleng and Jembrana Regency, is indeed the most vulnerable area to meteorological drought. This is shown in Table 1 upon the amount level of BNPB drought impact event record is just as much as average frequency of SPI3  $\leq -1$  on each station. Buleleng and Jembrana Regency do not have much drought resilience infrastructure like reservoir, integrated ground water pump, etc. [30]. Therefore, the level of meteorological drought events is just as much as the number of actual drought impact events. Meanwhile, Tabanan and Gianyar that have relatively low record of drought impact events even though the amount of SPI3  $\leq -1$  event is also high. These discrepancies might be because Tabanan and Gianyar already have enough drought resilience infrastructure [30]. Based on PCC ( $r$ ) and LGCT ( $p$ ) in Figure 3, Buleleng and Jembrana regency drought is highly caused by El Niño phenomenon rather than Positive IOD throughout 1991-2020. On the other hand, Karang Asem and Klungkung regency (including Penida Island) having relatively high amount of drought impact event record for relatively low amount of meteorological drought event (SPI  $\leq -1$ ) compared to Jembrana and Buleleng before. These findings need to be further studied of the propagation effect of

meteorological drought to in Bali and other factors like environmental characteristic, changes in land use, etc. [31]. That might worsen the propagation even without severe meteorological drought

#### 4.0 CONCLUSION

ENSO has the most influence on meteorological drought in Bali compared to IOD based on PCC  $^{\circ}$  value and LGCT ( $p$ ) value. ONI-SPI3 shows a higher PCC  $^{\circ}$  value in the gradation range -0.50 rather than DMI-SPI3 on range -0.25. ONI also shows a stronger Granger causality relationship to SPI3 with confidence level 95% with SPI3 average value, while DMI shows weak to no Granger causality relationship. However, IOD is not completely unrelated to the meteorological drought in Bali. These show that in 2019 the starting point of the drought is in eastern Bali with 1-month lag time after to DMI value rose. Furthermore, if confidence level is used in 90% for LGCT ( $p$ ) value, there is a slightly Granger causality relationship in some of areas in Bali. A good example of ENSO affecting drought in Bali area is in Jembrana and Buleleng regency. The amount of meteorological drought events and drought impact events in those 2 areas is similarly high each other. Furthermore, the PCC  $^{\circ}$  value and LGCT ( $p$ ) value show high correlation and Granger cause relationship each other.

In this study, ENSO and IOD are considered two different phenomena that have no relationship to each other. Further study of meteorological drought in Bali needs to be considered more variables. One of them is considering ENSO and IOD is related as dynamical anomaly phenomenon of Indian Ocean and Pacific Ocean interaction, and the other is climate change factor. Moreover, the water balance and the relationship to hydrological characteristics in Bali also need to be studied further. This is to find out how serious the water shortage in Bali is and its relationship to the meteorological drought phenomenon.

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#### Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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