Bulgarian Journal of Agricultural Science, 24 (No 5) 2018, 914–924

An analysis of drought and its relationship with an agricultural area in the watershed of Krueng Aceh, Indonesia

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Abstract

Azmeri & Syahrial, A. (2018). An analysis of drought and its relationship with an agricultural area in the watershed of Krueng Aceh, Indonesia. *Bulgarian Journal of Agricultural Science*, *24*(5), 914–924

In Indonesia, apart from Java Island, there is a scarcity of drought research. Therefore it is important to apply the results of the drought analysis, so as to anticipate an agricultural drought. This research aims are to calculate the drought index with the Standardized Precipitation Index (SPI), to compare SPI with the Southern Oscillation Index (SOI), Indian Ocean Dipole (IOD), river discharge and extensive rice fields affected by crop failure; to depict a map of drought spatial distribution. The worst agricultural drought value of SPI-6, displayed by Indrapuri post in November 2008, is about -5.13. Meanwhile SPI-12 showed the worst hydrological drought happening in November 2008 by -3.51 in Indrapuri post. The worst drought duration occurred in Blang Bintang, lasted for 34 months. The analysis results show that there is no significant relationship between the value of the SPI with SOI and IOD, so that it can be said that rainfall patterns in the watershed of Krueng Aceh are not influenced directly by the SOI or IOD. Relationship of the SPI with discharge is also not sufficiently significant, with the greatest relationship of 0.61 on Indrapuri post. The SPI value also does not show a direct relationship with rice fields affected by the drought.

Keywords: drought; SPI; SOI; IOD; agricultural drought; hydrological drought

Introduction

Drought is the genesis of a disaster that creeps up on us slowly without our realizing it, because it can only be experienced as an impact. It can manifest as a lower level of water in wells, rivers, lakes, and groundwater reducing land humidity which leads to plant stress causing them to die and will affect the water balance of irrigated agriculture (Ojeda-Bustamante et al., 2017). Climate change has affected the hydrological cycle (Woods et al., 2006), particularly water available for agricultural crops (Gawith et al., 2012; Rotich and Mulungu, 2017).

The drought in the area of Indonesia is influenced by climate change, significantly the difference in air pressure and air temperature between the Eastern Pacific Ocean measured in Tahiti, and the Western Pacific Ocean measured in Darwin, Australia. The difference in value of the average air pressure in Tahiti and Darwin is recorded in an index known as the Southern Oscillation Index (SOI) (Dahlman, 2009). This index can be used as a reference to calculate the relationship with the drought that has occurred.

Drought meteorology is significant related to the phenomenon of El-Nino. While a meteorological drought has a significant relationship with an agricultural one, proof of both is still required (Mladenova and Varlev, 2007; Adidarma et al., 2013;). Dai (2012), researcher at the National Center for Atmospheric Research (NCAR) in Colorado, USA, explained that due to the rise in global temperatures, the impact of climate change will increase in soildrought conditions in 30 years in most parts of the world. Adidarma et al. (2009) have studied the trend of lower rainfall in the dry season, and the possibility of intense dryness that became worse in some watersheds on Java Island, Indonesia. This research was based on the rainfall data of the years between 1916 and 2000. The results of research state that the phenomenon of increased dryness cannot be inferred merely from the tendency of heavy summer downpours. A drought that reduces the frequency of plentiful summer rain cannot be inferred from the tendency for more rain in the wet season.

Pratama (2014) conducted research on the analysis of drought using the Theory of Run on the watershed Ngrowo, Indonesia. Research results indicated the duration of the longest drought of 17 months with the greatest intensity and quantity of rain 2.303 mm, in 1998. The conclusions showed that meteorological drought is associated with hydrological drought, from a relationship between drought and the number of dischargecards in the river. In addition, meteorological drought also has a relationship with the SOI which is an indicator of the onset of El-Nino.

Method of Standardized Precipitation Index (SPI) can calculate various drought index time scale. At first the SPI is calculated for 3, 6, 12, 24 and 48 months. This time scale describes the impact of the drought on the availability of various water sources in accordance with the allocation. The SPI-1 or 3-monthly described the meteorological drought and observed the monitoring drought. The SPI-1 to 6 monthly was used for agricultural drought, and the SPI-12 to 24 monthly was used for analysis of hydrological drought and for catchment reservoirs design (Mckee et al., 1993).

Determination of scale (index) of drought can be measured by calculating the deviations of a long rainfall period (monthly) with a value of either normal/average rainfall condition or a threshold value (humidity) (Adidarma et al., 2011a, b). The threshold value can be a value set in accordance with the needs of the allocation. The value of humidity for rice is 150 mm/month and for coconut it is 70 mm/month (Oldeman et al., 1980), by assuming that the probability of the same rainfall is 75% which can fulfill the needs of water for rice plants of 220 mm/month and 120 mm/month for *palawija* (coarse grain). Consequently, a month is said to be wet when the rainfall is greater than 200 mm and dry when there is less than 100 mm.

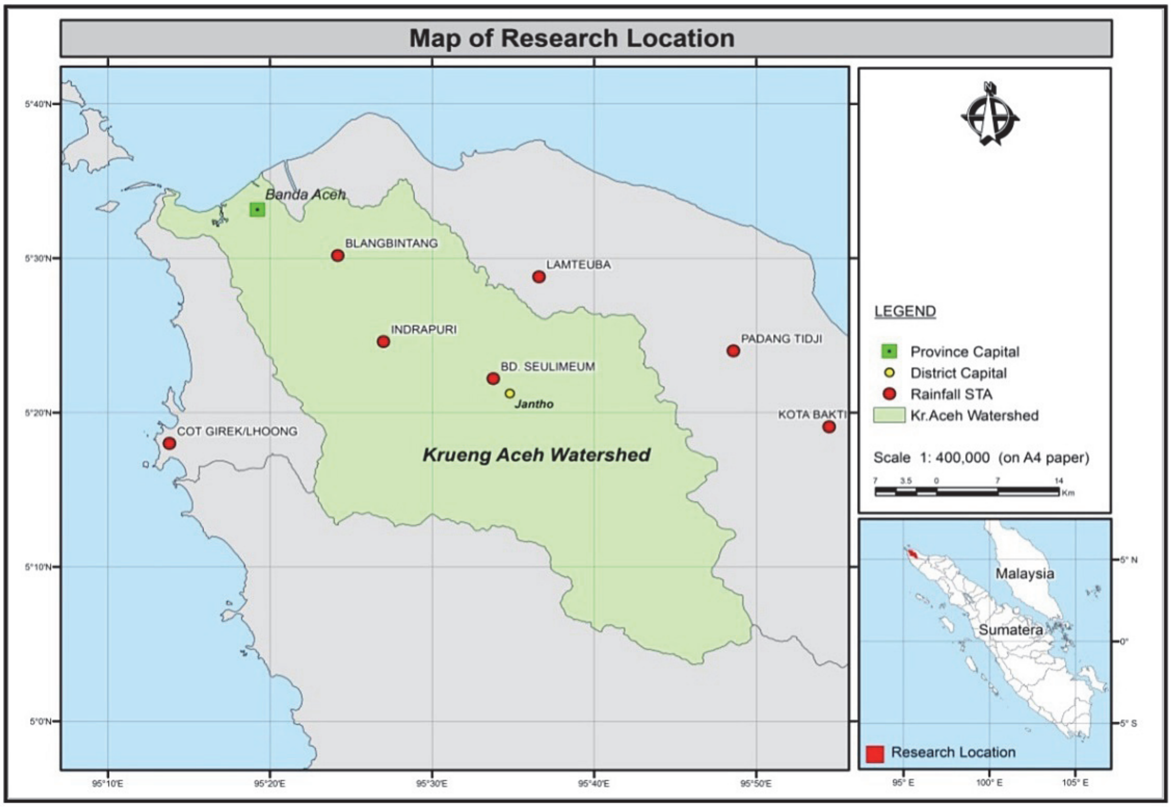

Fig. 1. Map of research location (*Source*: Public Work Office/Irrigation, 2017)

The agricultural sector as the largest water user becomes the most severely affected when catastrophic drought occurs. Climate change impacts more susceptible agricultural products, lowering the production of rice and coconuts (Mioduszewski, 2009).

At the moment, the calculation of the SPI outside Java Island (Indonesia) has not much done, particularly in Aceh province. Indonesian Agency for Meteorology, Climatology and Geophysics only do calculations for the SPI-3 monthly. Thus it is important to look at the relationship between the SPI and agriculture.

Data and Methods

The location of the study is in the Krueng Aceh watershed which is located in the Aceh Besar district, Aceh Province. Krueng Aceh watershed is located at the coordinates 5°35′34″ – 5°3′40″ Latitude North and 95°13′2″ – 95°49′46″ Longitude East. Figure 1 shows the position of rain posts that spread in and around the watershed of Krueng Aceh.

Data availability of sufficient rain especially in the province of Aceh for conducting an analysis of hydrology is extremely scarce. Military conflict has neglected monitoring posts and the tsunami disaster worsened conditions. Not all posts have complete data and time is required for data to be inputted. The missing rainfall data was recorded using the combination method (developed by a team of flood and drought specialists, HITA Office, Water Resources Center, the Ministry of Public Works). Table 1 shows the list of rainfall posts in Aceh Besar District.

The calculation of the SPI to a location is worked out on the basis of monthly rainfall data for the desired period. Rainfall data is adjusted to a type of Gamma distribution, then calculated within the parameters of the Probability Density Function (PDF). Next it is transformed to a normal distribution reading where the average SPI in a location is equal to zero. When the value of SPI is positive, it indicates that the rainfall is greater than the threshold. On the other hand, when the value of SPI is negative, rainfall is less than the threshold (Adidarma et al., 2011).

Table 1
List of rainfall posts

No.	Post Names	Coordinate	
		Latitute	Longitude
1	Blang Bintang	5° 30′ 12″ LU	95° 24′ 12″ BT
2	Kota Bakti	5° 16′ 0.93″ LU	95° 55′ 46.6″ BT
3	Lhoong	5° 18′ 00″ LU	95° 13′ 48,0″ BT
4	Seulimum	5° 22′ 12.9″ LU	95° 33′ 48,0″ BT
5	Indrapuri	5° 24′ 13.55″ LU	95° 27′ 51.23″ BT
6	Lam Teuba	5° 28′ 48,0″ LU	95° 36′ 36,0″ BT
7	Padang Tidji	5° 24′ 0″ LU	95° 48′ 36,0″ BT

Meteorological drought is defined based on the level of drought climate change based on a specific period of rainfall, compared to "normal" condition or averages duration of the dry period. While the agricultural drought related to the hydrological characteristics, where conditions are less rain (in the context of agriculture) is associated with the actual evapotranspirasi and potential ground water that shrink, characteristics of plants, and shrinking water flow of the river, reservoirs or ground water. Agriculture drought must be able to calculate the condition land humidity in the top soil at the time of planting. Therefore if the humidity of land in the top soil is not sufficient, it will decrease the harvest or even will happen *puso* conditions for rice (Adidarma et al., 2011).

Standardized Precipitation Index (SPI)

According to the guidelines of the Construction and Civil Building No. Pd T-02-2004-A 2004, about the calculation of the drought index using the Run theory, the drought index in each rainfall post is calculated using the Standardized Precipitation Index method. The calculation provides a drought index in 1-monthly, 3-monthly, 6-monthly and 12-monthly periods. The procedure for the calculation of the drought index with the SPI is based on the following:

1. The series of monthly rainfall data calculate data parameters for each of the same months in the form of:
   - mean
   - standard deviation
   - lambda = [stdev / (mean)^2],
   - beta = 1/lambda,
   - alpha = lambda x mean,
   - the amount of data (n),
   - the frequency of data with the value of "0" (m), and
   - probability (q) = m/n
2. Then the data is changed into a Gamma distribution to calculate the cumulative probability distribution of Gamma using the monthly parameters of alpha and beta in accordance with their monthly data.
3. Furthermore its probability is calculated with the formula of the "q (1-Q)*cumulative gamma probability".
4. Finally, the value of the drought index SPI is acquired by changing the data back to "normal distribution standards" by using the function of "norsinv".
5. For the SPI 3-monthly, 6-monthly and 12-monthly, the calculation is slightly different with the SPI 1-monthly, by summarize data by as much as 3 months, 6 months and 12 months that continue to be counted until the last data is recorded.
6. Parameters of the data for each month are also calculated for SPI 3-monthly, 6-monthly and 12-monthly.

Southern Oscillation Index (SOI) and Indian Ocean Dipole (IOD)

Southern Oscillation Index (SOI) describes the difference of average air pressure that is measured in Tahiti and Darwin, Australia. SOI value is measured based on the difference in air pressure above the monthly standardized mean sea level on each measurement station (Dahlman, 2009).

In general, the positive value of the SOI which is high and continuous for at least 2 months, influences the possibility of rain above the average in that year in the Western region of Indonesia including the SOI (occurs La Niña). In contrast, the negative value of the SOI which is great and continuous for at least 2 months, affects the likelihood of rain below average in the Western region of Indonesia including the SOI (occurs El Niño). Nevertheless, the relationship between the value of the SOI and amount of rainfall can vary depending on the weather and the local region. In other words, rainstorms can occur without La Niña or drought can occur without the El Niño. The location of the research also shows multiple origins of droughts (long negative SPI value) without the El Niño (indicated with a long negative SOI value).

The Indian Ocean Dipole (IOD) is determined on the difference of sea surface temperature in two areas (dipole), the Western Pole in the Arabian Sea (Western Indian Ocean), and the Pole on the Western side of Indian Ocean in East Indonesia. The IOD influences weather in Australia and surrounding countries, and significantly changes precipitation in these areas (Saji et al., 1999).

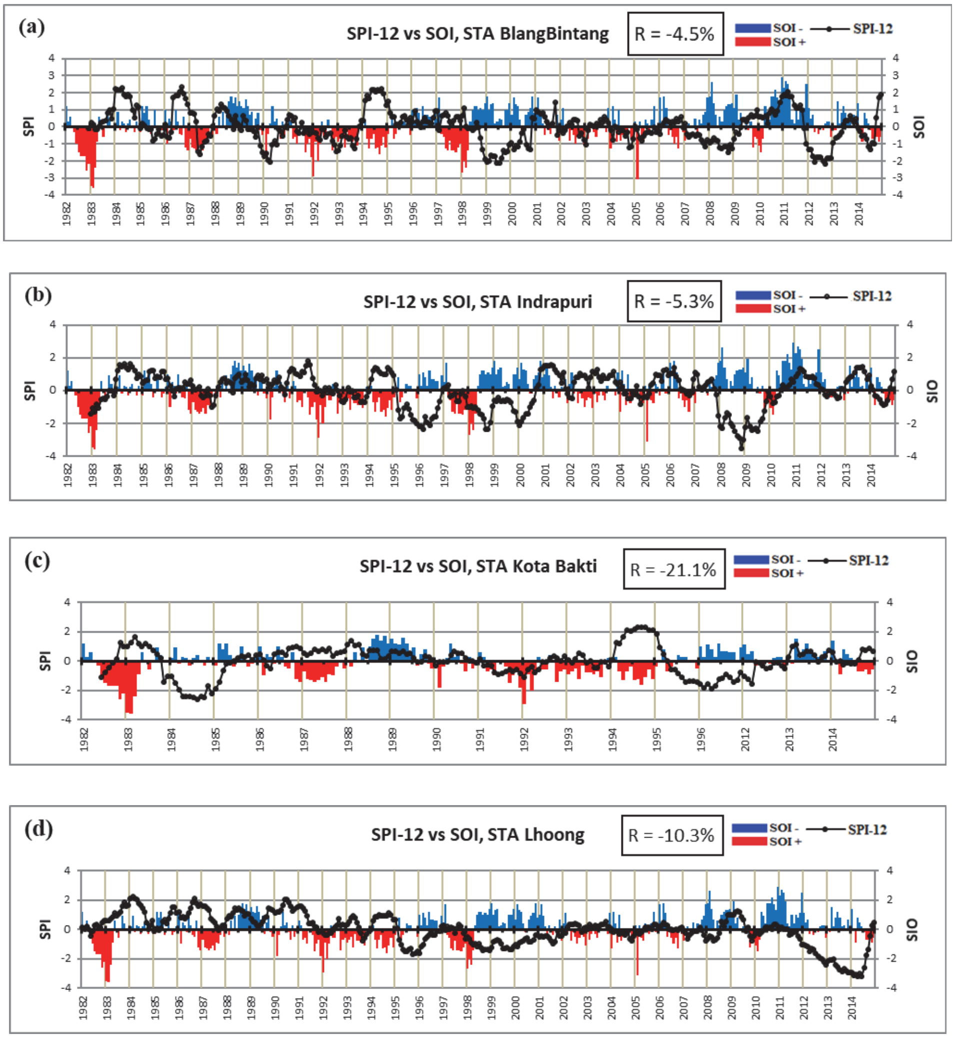

Fig. 2. Relationship between SPI-12 and SOI

Results and Discussion

Relationship between SPI and SOI

Drought analysis of SPI-1, SPI-3 and SPI-6 could not indicate the drought accurately. The drought analysis of SPI-12 (specificly to the condition of the hydrological drought) showed a relationship between the genesis drought (long negative SPI) and the possibility of whether El Niño that occured or not based on the value of the SPI.

From 7 posts, analysis is only done in 4 posts. Four posts have the latest rain data, while other posts only have data before 2014. Figure 2 describes the relationship between the SPI-12 and SOI.

The graph presented in Fig. 2 refers to the relationship between the SPI-12 and the SOI value, which shows that the value of the long negative SPI does not indicate any relationship with the value of the long negative SOI. Returns the correlation coefficient of the array 1 and array 2 cell ranges. Use the correlation coefficient to determine the relationship between two properties. The equation for the correlation coefficient is:

$$\text{Correl}\ (X,Y)=\frac{\sum x(x-\bar{x})(y-\bar{y})}{\sqrt{(x-\bar{x})^2(y-\bar{y})^2}},$$

where: $\sum x$ = total number of variabel X; $\sum y$ = total number of variabel Y; = total average of variabel X; and = total average of variabel Y.

The value of R in each graph in Fig. 2 shows how significant is the relationship between the SPI-12 and the SOI. The larger the value of R the relation is significant. Consequently, it can be said that the climate in the location of the study is not influenced directly by the SOI. It can be stated that the drought in the location of the study often occurs without *El Niño*.

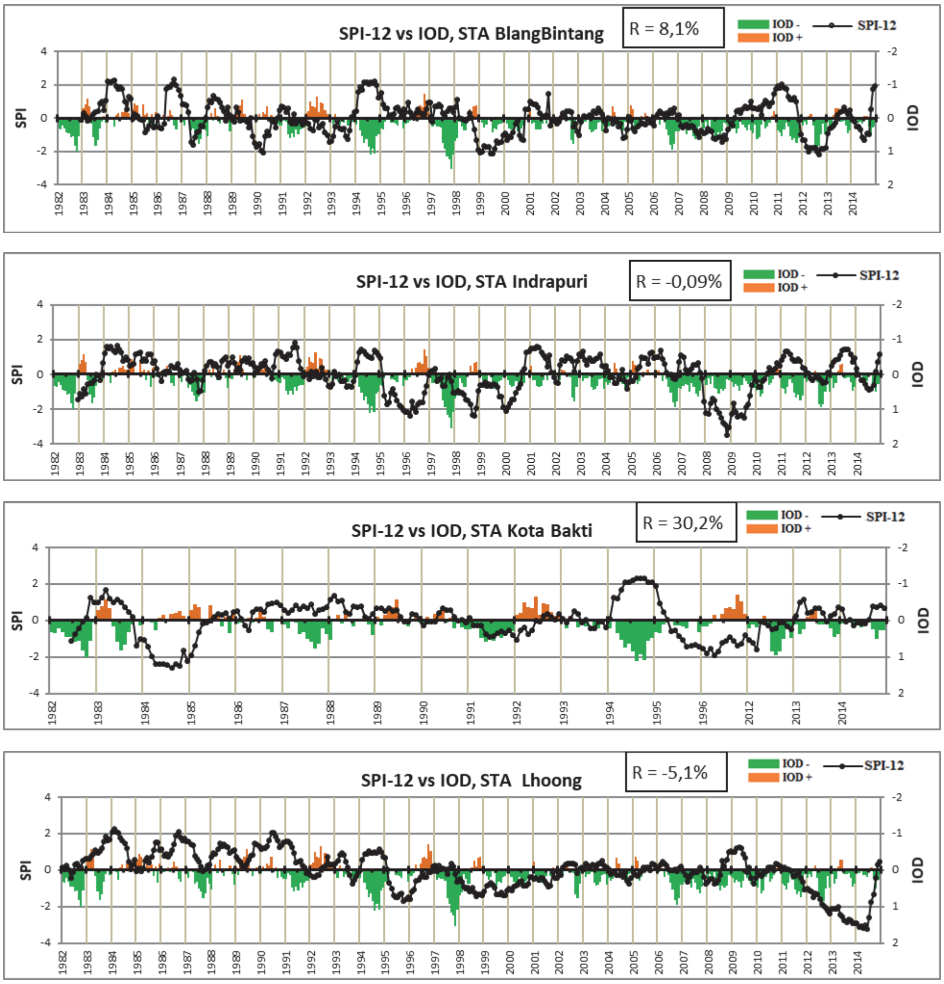

Fig. 3. Relationship between SPI-12 and IOD

Table 2
Classification of the wetness and drought level according to the value of SPI

The value of SPI	Classification
2.00 or >2.00	Extremly wet
1.50 –1.99	Very wet
1.00 – 1.49	Moderately Wet
(-0.99) – 0.99	Near normal
(-1.00) – (-1.49)	Moderately dry
(-1.50) – (-1.99)	Severely dry
(-2.00) or < (-2.00)	Extremely Dry

Source: Mckee et al. (1993)

Relationship between SPI and IOD

In contrast to the SOI, in the IOD, a positive value indicates the possibility of drought, while negative numbers describe the excess of rainfall. In other words, a lengthy positive value of IOD shows the lack of rainfall which impacts on a long disaster drought.

Fig. 3 shows that there is no significant relationship between the value of the IOD and the index value of the SPI-12. According to the graph, there is only a little data that shows the period of the months with the value of the long negative SPI, that correlate with the value of the long positive IOD.

The Blang Bintang post indicated no significant relationship with relationship R = 8.1%. In the Indrapuri post, there was a no significant relationship between the SPI-12 and the IOD with R = – 0.09%. In the Kota Bakti post, there was sig-

Table 3. Analysis of annual rainfall character in rainfall post

Year	BlangBintang		Indrapuri		Kota Bakti		Lhoong		Average	
1982	Dry	-1.42%	Dry	-27.99%	Wet	0.3	Wet	15.14%	0.04%	Wet
1983	Wet	18.19%	Wet	13.02%	Dry	-0.2	Wet	49.42%	5.33%	Wet
1984	Wet	20.58%	Wet	16.88%	Dry	-0.5	Wet	14.85%	-8.25%	Dry
1985	Dry	-8.05%	Wet	13.08%	Wet	0.1	Wet	30.89%	9.38%	Wet
1986	Wet	23.89%	Wet	11.69%	Wet	0.2	Wet	52.53%	19.02%	Wet
1987	Wet	0.58%	Dry	-7.97%	Wet	0.2	Wet	5.89%	-5.48%	Dry
1988	Wet	3.50%	Wet	9.58%	Wet	0.1	Wet	30.35%	23.36%	Wet
1989	Dry	-22.59%	Wet	13.26%	Wet	0.0	Wet	37.46%	6.72%	Wet
1990	Wet	7.73%	Wet	28.82%	Dry	0.0	Wet	44.03%	6.88%	Wet
1991	Dry	-3.30%	Dry	-3.38%	Dry	-0.2	Dry	-4.77%	-8.58%	Dry
1992	Dry	-21.93%	Dry	-14.36%	Wet	0.1	Wet	5.94%	-9.24%	Dry
1993	Wet	6.20%	Dry	-9.05%	Dry	-0.1	Dry	-4.45%	8.03%	Wet
1994	Wet	22.07%	Wet	22.37%	Wet	0.6	Wet	18.15%	25.63%	Wet
1995	Wet	9.33%	Dry	-37.52%	Dry	-0.3	Dry	-36.49%	-12.72%	Dry
1996	Wet	16.15%	Dry	-1.03%	Dry	-0.2	Wet	4.27%	3.46%	Wet
1997	Wet	6.04%	Dry	-21.05%			Dry	-17.82%	-5.58%	Dry
1998	Dry	-27.82%	Dry	-20.03%			Dry	-34.43%	-21.10%	Dry
1999	Dry	-15.95%	Dry	-35.17%			Dry	-28.90%	-26.67%	Dry
2000	Wet	8.62%	Wet	28.10%			Dry	-11.31%	8.47%	Wet
2001	Dry	-2.82%	Dry	-5.19%			Dry	-13.23%	-7.08%	Dry
2002	Dry	-12.23%	Wet	24.12%			Wet	1.81%	4.57%	Wet
2003	Wet	4.42%	Wet	7.47%			Wet	2.37%	4.75%	Wet
2004	Dry	-10.73%	Dry	-9.90%			Dry	-13.31%	-11.31%	Dry
2005	Dry	-3.99%	Wet	18.69%			Wet	3.40%	12.30%	Wet
2006	Dry	-0.02%	Wet	13.44%			Wet	2.94%	12.92%	Wet
2007	Dry	-12.09%	Dry	-30.22%			Dry	-20.92%	-11.36%	Dry
2008	Dry	-19.04%	Dry	-51.27%			Wet	28.35%	2.75%	Wet
2009	Wet	17.21%	Dry	-3.50%			Dry	-13.31%	-3.18%	Dry
2010	Wet	31.88%	Wet	8.98%			Wet	3.40%	4.99%	Wet
2011	Dry	-15.60%	Wet	5.60%			Dry	-27.01%	-12.46%	Dry
2012	Dry	-26.91%	Dry	-0.61%	Dry	-13.43%	Dry	-52.42%	-21.94%	Dry
2013	Wet	8.10%	Wet	19.35%	Wet	17.75%	Dry	-60.68%	1.69%	Wet
2014	Wet	34.71%	Wet	23.76%	Wet	16.67%	Wet	10.85%	20.47%	Wet

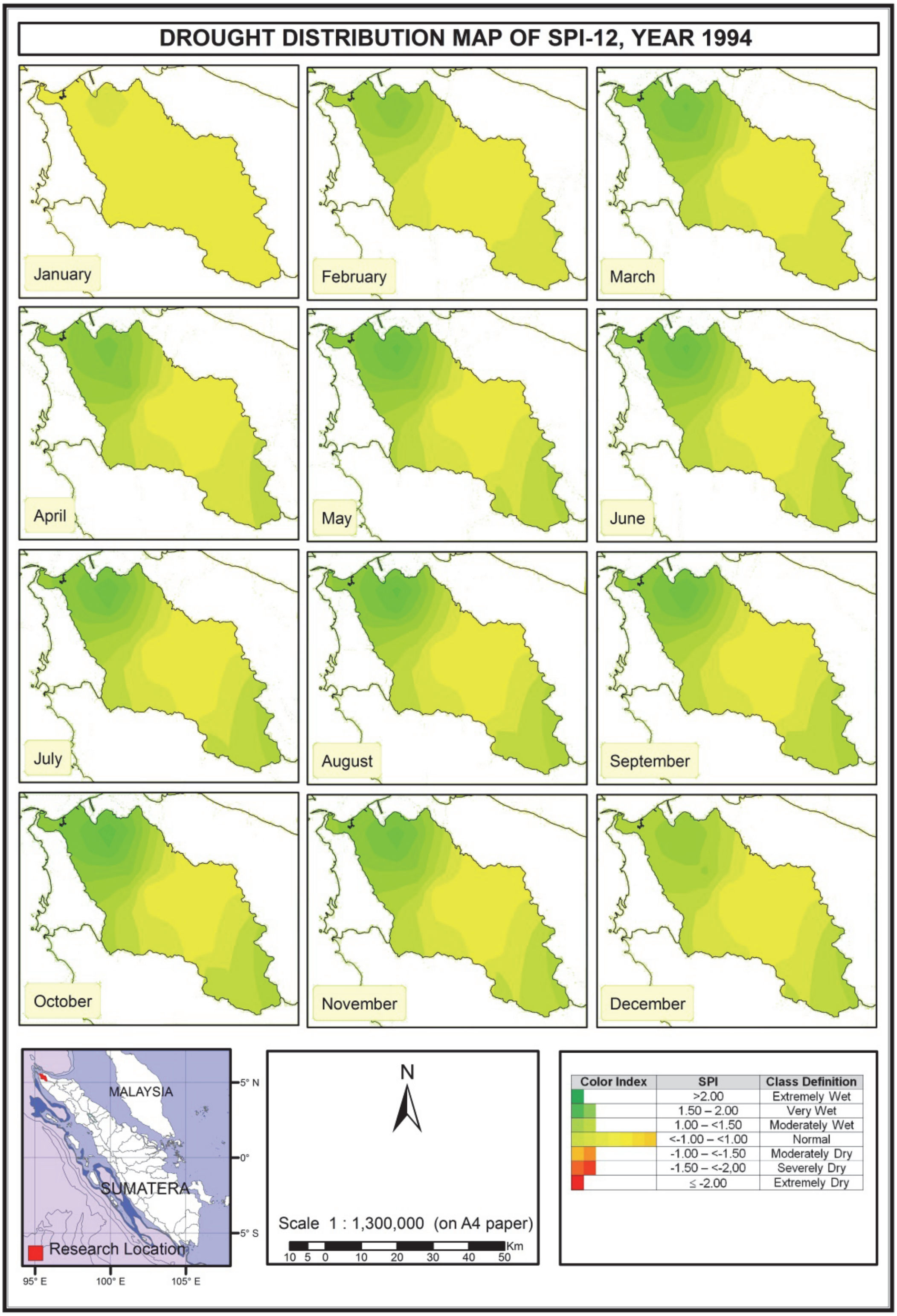

Fig. 4. Map of drought spatial distribution in a wet year (1994)

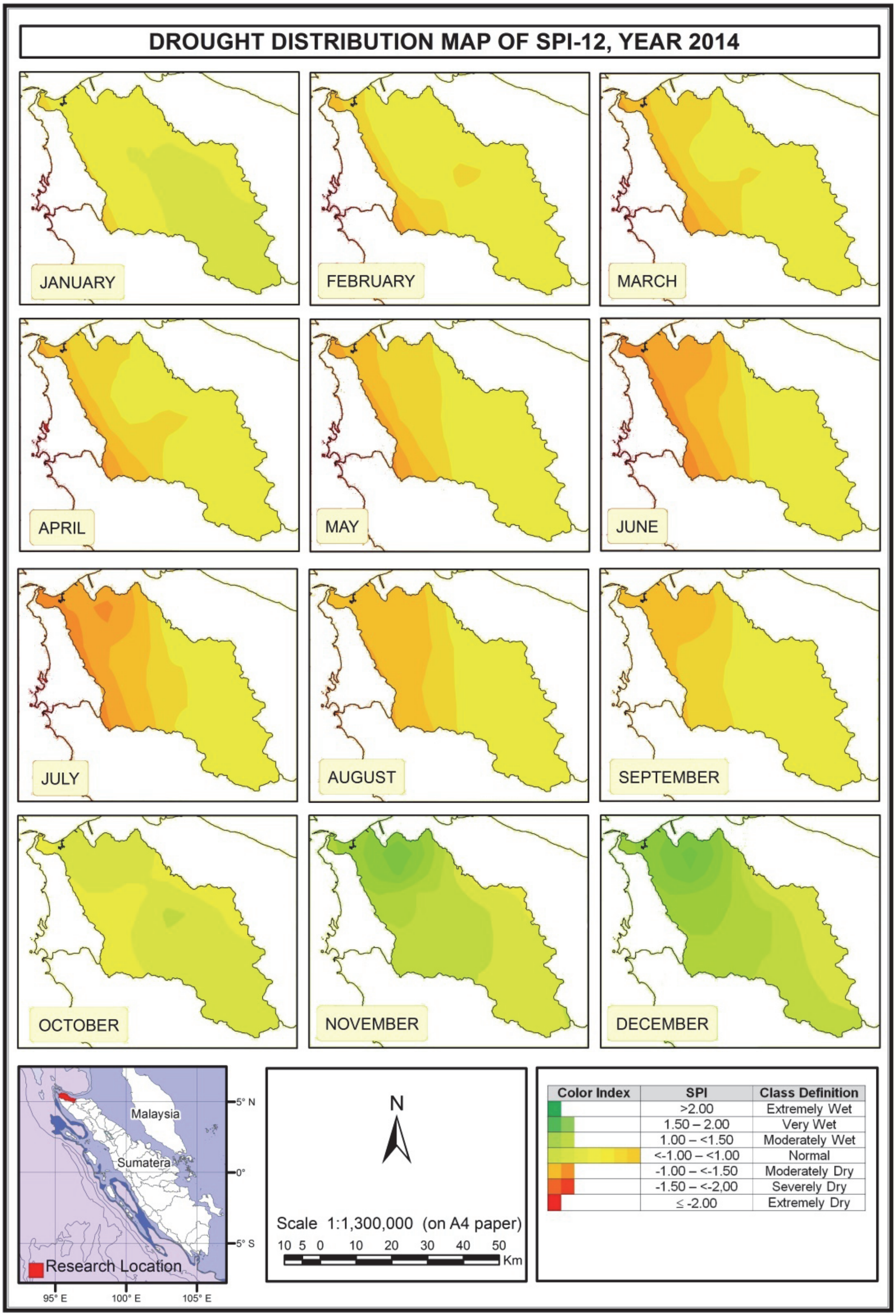

Fig. 5. Map of drought spatial distribution in dry year (1998)

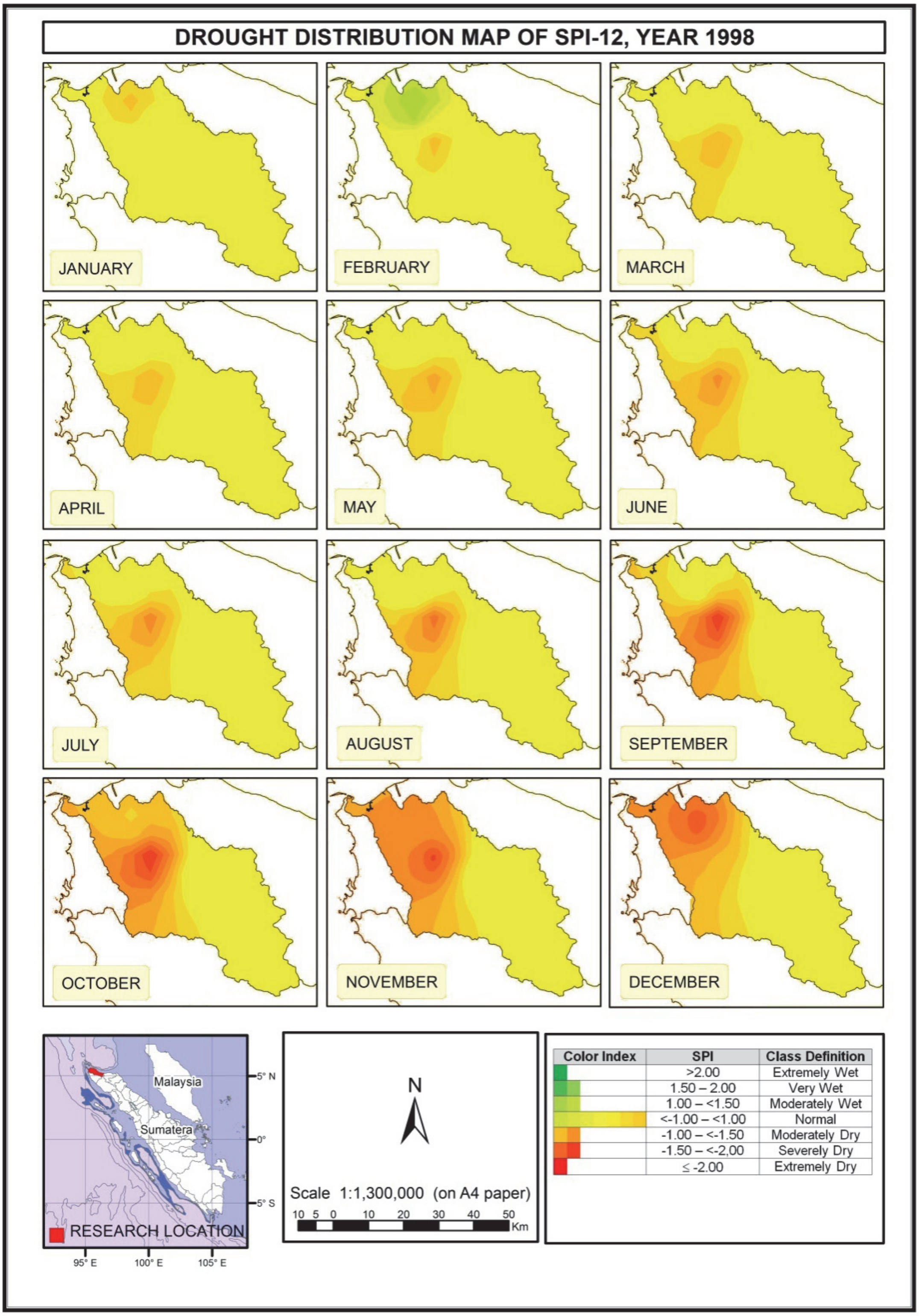

Fig. 6. Map of drought spatial distribution in 2014

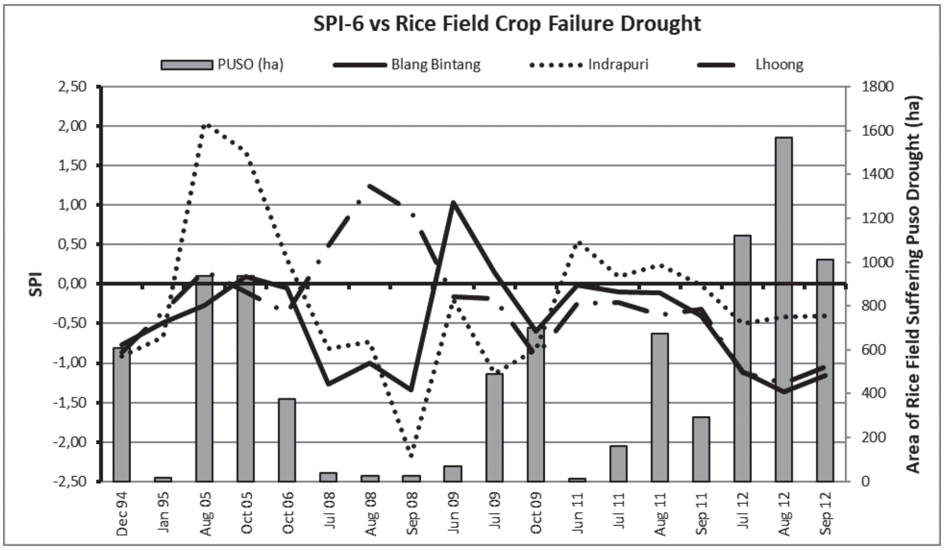

Fig. 7. Relationship graph between monthly SPI-6 value and rice field area that suffering crop failure drought

nificant with R = 30.2%. The Lhoong post shows no significant relationship between SPI-12 and IOD with R = – 5,1%.

Drought spatial distribution

The monthly drought map is composed of multiple years, based on the criteria of extreme wet years (1994), a dry year (1998), and the final year (2014). This map is presented based on the results of the calculation of the droughtindex with the Standardized Precipitation Index method that is drawn using the software ArcGIS.

McKee et al. (1993) classify the criteria of drought/wetness level based on the level of rain intensity by dividing it in some level of index scale (Standardized Surface Index) to the time scale of certain events, as outlined in Table 2.

The years are determined of extreme, dry and normal years based on the amount of rain in each post's annual rainfall. The same data is then compared to the amount of average rainfall, so that the percentage of the rain on the post may be obtained. The results of the annual rainfall analysis of each post are presented in Table 3.

The map of the spread of drought for a drought index of SPI-12 in 1994 in Fig. 4 shows that the dominant wet phenomenon (extreme wet) occurs throughout the year, namely that the rainfall in 1994 was very high.

Fig. 5 shows a map of the spread of drought SPI-12 in 1998, which shows that from January to July, rainfall remained normal. The rainfall was less from August to December, so that a drought occurred in these months.

A map of the spread of drought for 2014 in Fig. 6 shows that there is a decline of rainfall from January to September (drought). October showed normal conditions, while rainfall in November and December had already returned to normal, wet conditions.

Crop failure drought vs SOI-6

The value of the SPI that describes agricultural drought is shown on the SPI-6. If it is correlated with the impact of drought in agriculture, it is the same as the number of hectares of rice fields affected by drought, experiencing the crop failure. The number of data fields affected by crop failure drought was issued by the Department of Agriculture, the Directorate for the protection of the food crops, Indonesia.

Based on the data obtained, drought in the Aceh Besar District occurred in late 1994, 2005, 2006, 2009, 2011 and 2012. While the value of the SPI-6 shows a lengthy period of drought from 2011 to 2012 in the Blang Bintang post, in Indrapuri and Lhoong Posts, the value of SPI-6 on the period did not show the drought. This data shows that there is no significant relationship between the value of the SPI-6 and agricultural drought. Only in the Blang Bintang post did the index value of SPI-6 in 2011 and 2012 have a positive relationship with widespread rice affected by a crop failure (Fig. 7).

Conclusions

The conlusions of research conducted in the location of the studies are:

The worst drought value of SPI-1 occurred in Blang Bintang post of -4.45 in March 1998 for the data period from 1981 to 2014.

The worst drought value SPI-3 happened in Indrapuri post of -5.12 in November 2008 for data period from 1981 to 2014.

The worst value of SPI-6 appears in November 2008 of -5.13 on Indrapuri post for the data period from 1981 to 2014.

The worst drought value of SPI-12 took place in November 2008, with -3.51 in the Indrapuri post for the data period from 1981 to 2014.

According to the data from the entire rainfall posts, it shows that there is no significant relationship between the value of the SPI with the value of the SOI and the IOD. Rainfall patterns in the location of the study are not influenced directly by the SOI or the IOD**.**

The relationship between the value of SPI-6 and the selected rainfall posts does not show a significant relationship with genesis drought, indicated by the number of widespread rice fields affected by a crop failure drought.

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Received*:* October 27, 2017; ***Accepted****:* January 5, 2018; ***Published****:* November 2, 2018