Analysis of relationship between meteorological and agricultural drought using standardized precipitation index and vegetation health index

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Abstract. Agricultural drought is closely related to meteorological drought in which the agricultural drought is an impact of meteorological drought. This study aim to understand the duration, spatial extent, severity and lag time of meteorological and agricultural drought during El Niño years. The data used in this study are monthly data of CHIPRS and MODIS. Meteorological drought and agricultural drought are intensified in the El Niño years. The duration of meteorological drought is different in each region but generally occurs during June to November. Agricultural drought mostly occurs from August to November. Spatially, meteorological drought and agricultural drought in 2015 has wider extent and higher severity (SPI <-2 and VHI <10) than in 2002. Agricultural drought generally intensified in areas that have monsoonal rainfall type such as Java, Bali, Nusa Tenggara, Lampung, southern part of Kalimantan, and southern part of Sulawesi. We found that VHI is significantly correlated with SPI-3 reach 58% of the total area of Indonesia. It means rainfall deficit during three months has a significant impact on agricultural drought in Indonesia. In general, SPI-3 and VHI clearly explain the relationship between meteorological drought and agricultural drought in Indonesia.

1. Introduction

El Niño is widely known as global-scale climate anomalies which clearly modulates rainfall anomalies in many parts of the world including Indonesia [1]. Decreasing rainfall during El Niño frequently causes dryness over major part of Indonesia. In Indonesia some extreme drought occured simultaneously with El Niño event such as in 1997/1998, 2002/2006, 2006/2007, and 2009/2010 [2]. Indonesian National Board for Disaster Management (BNPB) also mentioned that El Niño in 2015 resulted in Puso in 111,000 ha farming area [3].

Drought has a significant impact on the economic, agriculture, environment, and social. Drought event during El Niño 2002 caused a Puso in 42,000 ha of paddy fields in Java [4]. Monitoring drought needs to be done to minimize such drought impact. Various drought indices have been developed by a number of previous studies to determine the duration and severity of drought [5]. These indices have been developed based on different parameters so that each drought indices reflects different drought conditions.

Drought indices is widely applied for monitoring drought are Standardized Precipitation Index (SPI) and the Vegetation Health Index (VHI) [6-8]. SPI is a meteorological drought index that shows level of drought due to rainfall deficit while the VHI is an agriculture drought index based on remote sensing that shows stress level of crops due to drought. VHI is constructed by combining the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI) [6-10].

Agricultural drought is closely related to meteorological drought in which the agricultural drought is basically the impact of meteorological drought. In general, plants do not respond to the meteorological drought directly. It seems there is a lag time between meteorological drought and agricultural drought. Therefore, the objectives of this study are (1) to identify the duration, spatial extent, and severity of drought and (2) to determine lag time of meteorological drought and agricultural drought in Indonesia during El Niño events.

2. Methodology

2.1. *Standardized Precipitation Index*

SPI is calculated in different time scale 1,3,6,9, and 12 months (SPI-, SPI-3, SPI-6, SPI-9 and SPI-12) based on CHIRPS data. CHIPRS is rainfall data set incorporating infrared Cold Cloud Duration (CCD) observation and in-situ stasion data for trend analysis and seasonal drought monitoring [11]. SPI calculation requires historical precipitation data at least 30 years. So that, CHRIPS data from 1981 to 2015 are used to do the calculation. The SPI calculation is conductedby following McKee *et.al* (1993) [12]. Meteorological drought category based on SPI shown in Table 1.

Table 1. Classification of drought severity by WMO [13]

SPI	Category
-1,0 < SPI ≤ 1,0	Normal
-1,5 < SPI ≤ -1,0	Moderate
-2,0 < SPI ≤ -1,5	Severe
SPI < -2,0	Extreme

2.2. *Vegetation Health Index*

MODIS data that consist of Enhanced Vegetation Index (EVI) and Land Surface Temperature (LST) are used to calculate VCI and TCI, respectively [8].We usetime series data from 2001 to 2015 to calculate their minimum and maximum values. The calculation of VCI and TCI is shown byfollowing equations:

$$\mathrm{VCI} = 100 \text{ x } \frac{\mathrm{E} - \mathrm{E_{min}}}{\mathrm{E_{max}} - \mathrm{E_{min}}} \quad (1)$$

where E is EVI value of a given month. E_{min} and E_{max} denote the maximum and minimum EVI values, respectively, for the month from multiyear time series.

$$\mathrm{TCI} = \frac{\mathrm{L_{max}} - \mathrm{L}}{\mathrm{L_{max}} - \mathrm{L_{min}}} \text{ x } 100 \quad (2)$$

where L is LST value of a given month. L_{min} and L_{max} denote the maximum and minimum LST values, respectively, for the month from multiyear time series. VHI are calculated based on VCI and TCI value using equation 3 [10]

$$\mathrm{VHI} = (0.5 \text{ x } \mathrm{VCI}) + (0.5 \text{ x } \mathrm{TCI}) \quad (3)$$

Agricultural drought classified into five category shown in Table 2 [10].

Table 2. Agricultural drought category besed on VHI

VHI	Category
< 10	Extreme
< 20	Severe
< 30	Moderate
< 40	Mild
>40	No Drought

2.3. *Correlation analysis between SPI and VHI*

Correlation analysis is conducted spatially between SPI and VHI over Indonesia region.This analysis is used to determine the time lag between meteorological drought and agricultural drought over the region.

3. Result and Discussion

3.1. *Meteorological Drought*

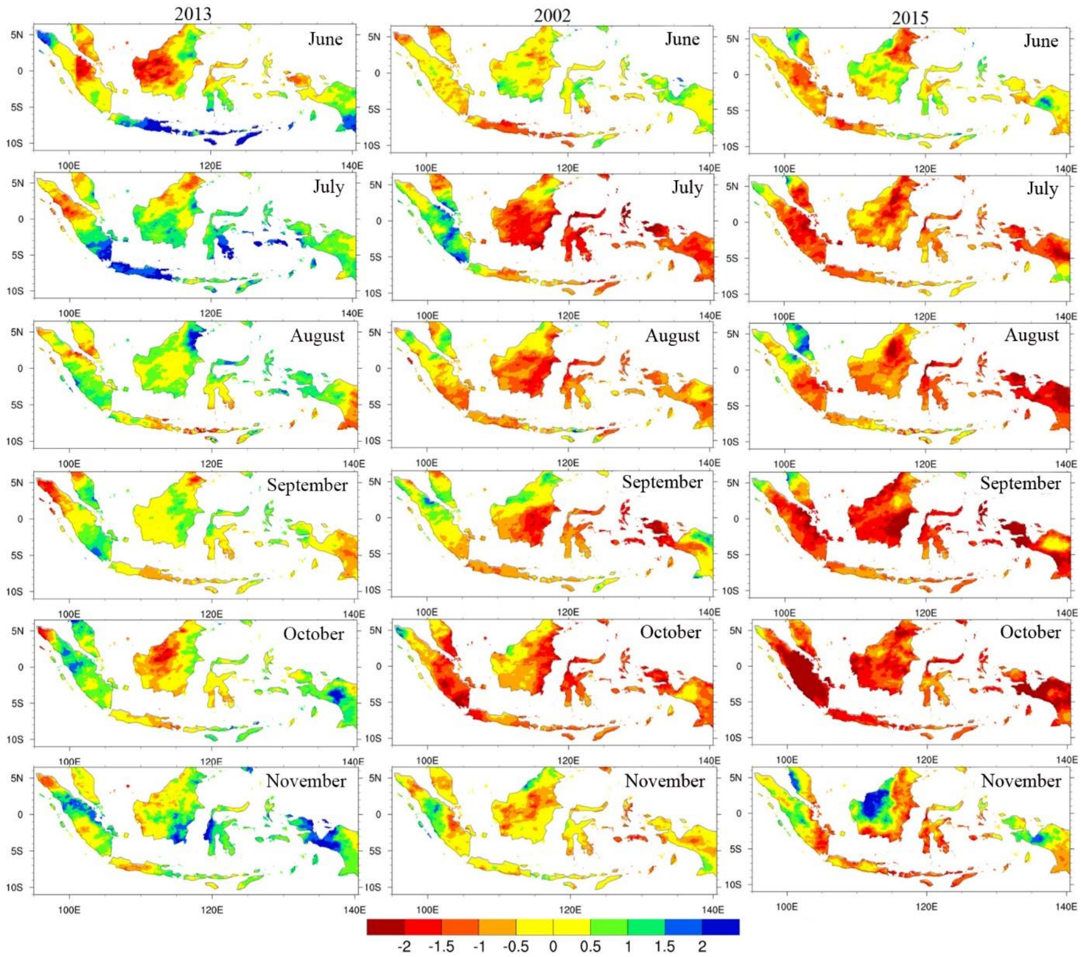

Figure 1. Spatial distribution of SPI in normal year(2013), weak El Niño (2002), and Strong El Niño (2015)

Meteorological drought is analyzed based on 1-month SPI (SPI-1). SPI-1 has significant correlation with rainfall so it is more appropriate to use it to analysis the meteorological drought [14]. The calculation of SPI-1 was done from 1981 to 2015. However, this study focuses on the drought conditions that occurred in 2002, 2013 and 2015. SPI-1 in 2002, 2013 and 2015 was chosen to explain the spatial distribution of drought in Indonesia during weak El Niño (2002), normal (2013), and a strong El Niño (2015).

El Niño has significant impact on the occurrence of meteorological drought in Indonesia [2]. In a normal year (2013), most of regions in Indonesiaare not affected by drought (see Figure 1). Drought occurs only in some parts of southern Indonesia (e.g. Java, Bali, Nusa Tenggara) and some part of northern Indonesia (e.g. north Sumatera and west Kalimantan). Southern region of Indonesia experienced drought from August to November, while the northern part of Indonesia such as Sumatera and Kalimantan experience drought from June to November. Moderate to extreme drought occured in this year.

Drought during weak El Niño (2002) was not spread uniformly across Indonesia (see Figure 1). Southern part of Indonesia experienced drought earlier than other region that is started from June. In addtion, Kalimantan, Sulawesi, and Papua experienced drought from July and some part of Sumatera experienced drought from August and reachits peakin October. In general, the drought is in the category of moderate to extreme drought with dominated by strong drought.

Drought in a strong El Niño (2015) occured almost over the regions during July to October as seen in Figure 1. In June, drought has occured only in Java and Sumatra, while in November drought occured only in the southern part of Indonesia. The peak of the drought observed in October. In general, the drought is in the category of moderate to extreme drought.

3.2. Agricultural Drought

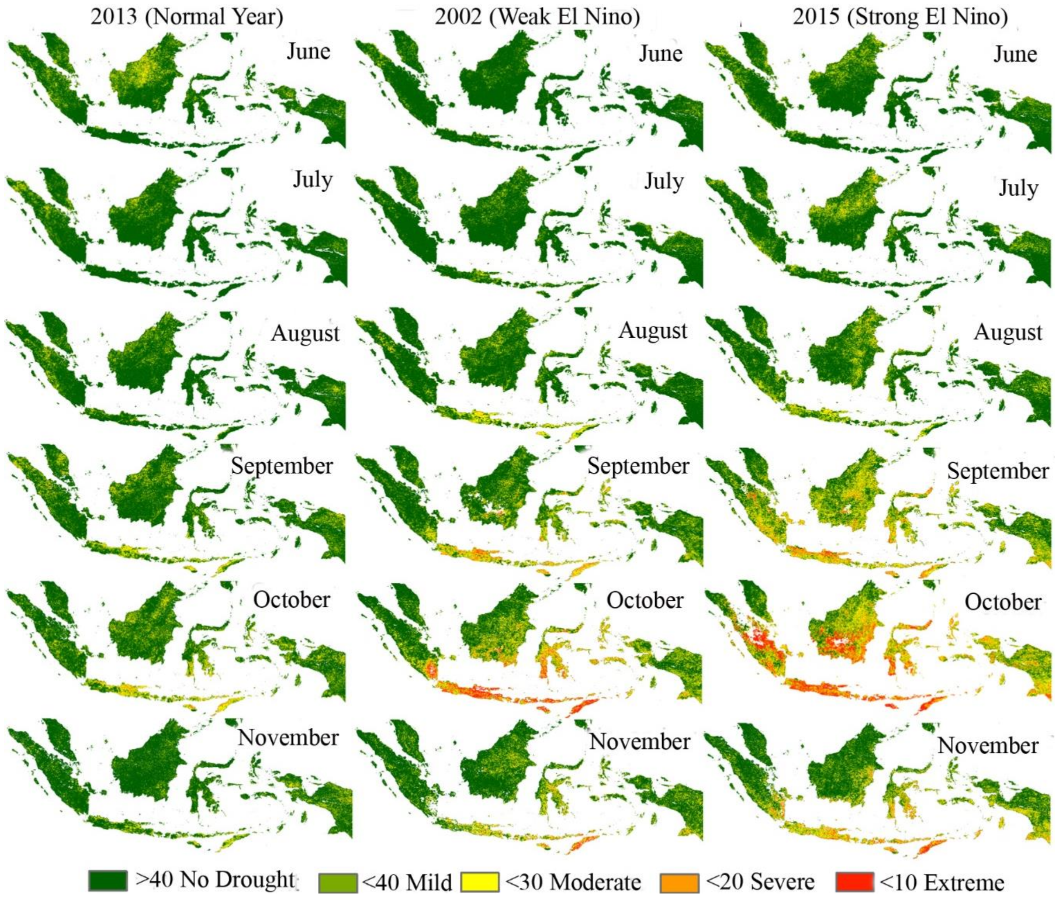

Figure 2. Spatial distribution of VHI in normal year(2013), weak El Niño (2002), and Strong El Niño (2015)

Decreasing levels of soil water or water stress can causes transpiration, photosynthesis, and retrieval of ions decrease that ultimately lead to impair growth and development of plants [15]. Reducing soil water content in constantly lead to agricultural drought [7]. This study used VHI to understand the duration, spatial distribution, and severity or category of agricultural drought. As well as SPI-1, VHI in 2002, 2013 and 2015 were chosen to determine the spatial distribution of agricultural drought in Indonesia during weak El Niño (2002), normal (2013), and strong El Niño (2015). Figures 2 show spatial distribution of VHI during normal year, weak El Niño, and Strong El Niño.

Agricultural drought in Indonesia is generally in the category of moderate to severe in the El Niño year. In 2013, drought observed from September to October in category mild to moderateespecially in the southern part of Indonesia. While in 2002, the drought started from August to November where drought dominantly occured in the southern part of Indonesia such as Java, Bali, Nusa Tenggara, southern part of Kalimantan, and southern part of Sulawesi. In this year, drought occurred in the category of mild to extreme in which extreme droughts observed in October. Moreover, drought occurred from August to November in mild to extreme category during 2015 which extreme drought is dominant in October. In all cases (2002, 2013, and 2015) drought were observed in the southern part of Indonesia. Due tomost of the region are dominanted by crops. Wang and Liu (2014) pointed out that crops area more quickly respond to drought than the forest [9].

3.3. Relationship between Meteorological and Agricultural Drought

Meteorological drought and agricultural drought generally has lagged in time [9]. It is exist due to soil water content is not reduced directly when rainfallgradually decreased. Spatially SPI-1, SPI-3, SPI-6, SPI-9, and SPI-12 are positively correlated with VHI in most Indonesian regionas seen in Figure 3. The correlation coefficient has increased from SPI-1 to SPI-3, then tend to be declined following the increase in time scale. Percentage of coveragewith significant correlation coefficient also increased from SPI-1 to SPI-3, then gradually decline following the increase in the time scale (Table 3).

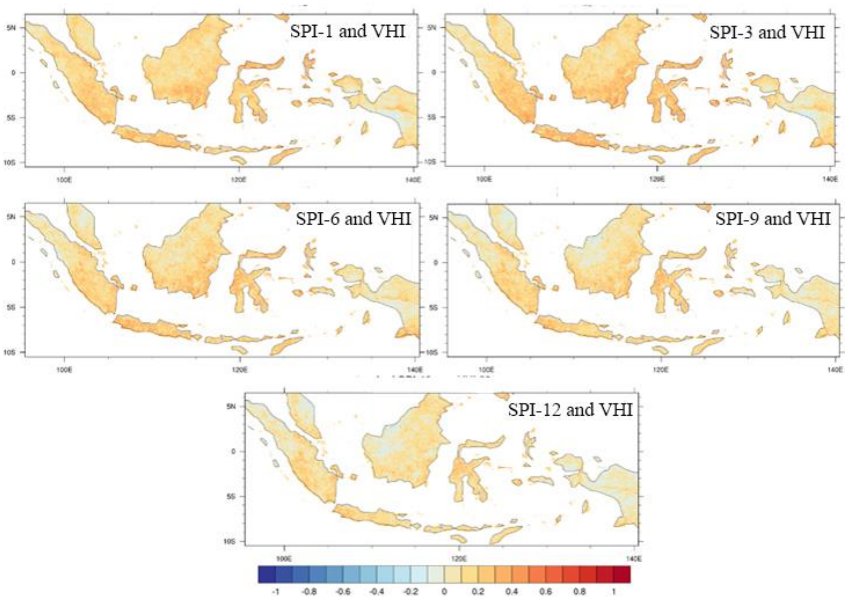

Figure3. Spatial correlation between SPI time scales and VHI

The coefficient correlation between the SPI-3 and VHI is 0.63 with significant at 99% level. The high coeficcient correlation covers about 58% of Indonesian region. It implies that the total deficit of rainfall for three months giving a significant impact on agricultural drought or it can be speculated that the lag time between meteorological and agriculture drought is about three months. Significant coefficient correlation values on SPI-3 and VHI are common in the southern part of Indonesia. This might be explained that the southern part of Indonesia are mostly center for crop production. This finding is agreed with previous studies (e.g. Wang et al, 2014; Huang et al, 2015). They pointed out crops respond to the drought after a rainfall deficit for three months [9,16].

Table 3. Data of correlation between SPI and VHI

Correlation	Maximum Correlation Value	Minimum Correlation Value	Percentage of coverage with significant correlation: Level 95%	Level 99%	Total
SPI-1 and VHI	0,55	-0,33	19%	38%	57%
SPI-3 and VHI	0,63	-0,32	15%	43%	58%
SPI-6 and VHI	0,58	-0,35	16%	31%	47%
SPI-9 and VHI	0,58	-0,47	15%	24%	39%
SPI-12 and VHI	0,61	-0,5	13%	15%	28%

Table 4. Coefficient correlation betweenSPI and VHI in some territory and containing note[a]

Territory	SPI-1 and VHI	SPI-3 and VHI	SPI-6 and VHI	SPI-9 and VHI	SPI-12 and VHI
Bali	0,34**	0,37**	0,32**	0,25 **	0,21**
Demak	0,14	0,19*	0,16 *	0,13	0,13
Kediri	0,25 **	0,30 **	0,21**	0,12	0,08
Cianjur	0,19 *	0,23 **	0,19 *	0,19 *	0,17 *
Progo	0,29 **	0,38 **	0,32 **	0,18 *	0,17 *
Lamongan	0,09	0,11	0,06	0,01	-0,01
Karawang	-0,01	0,05	0,07	0,05	0,09

[a]Note are referenced using alpha superscripts
*(**)correlation with significant level 95% (99%)

Mostly paddy fields in Indonesia is located in southern part and 40% centered on Java Island [17]. Territories of Java and Bali are choosen to get more detail about the correlation between SPI and VHI in paddy field. The correlation between SPI and VHI in paddy fields in most areas of Java and Bali (see Table 4) also show that the correlation increases in 3-months scale (SPI-3). Moreover, the coefficient correlation gradually decreased in SPI-6, SPI-9, and SPI-12. We noted that Karawang has a different pattern due towell-maintenance dirrigation system. Again, Table 4 shows the higher coefficient correlation between SPI dan VHI is in 3-months scale (SPI-3). It shows that the agricultural drought, especially in crop land, occurs after rainfall deficit for three months. We speculated that in generally agricultural drought in the majority of land crop has 3 months behind the occurrence of meteorological drought.

4. Conclusion

Meteorological drought and agricultural drought in Indonesia is more intensive during the El Niño years. The duration of meteorological drought is different in each region but generally observe during June to November. However, agricultural drought mostly occurs from August to November. In strong El Niño (2015), we found wider extent and higher severity of meteorological drought than in weak El Niño (2002). Areal extent and severity of meteorogical drought generally is increased in each month and reached its peak in October. Agricultural drought in strong El Niño (2015) also has wider areal extent and higher severity compared to weak El Niño (2002). The intensive agricultural drought mostly occurs in the areas with monsoonal precipitation such as Java, Bali, Nusa Tenggara, Lampung, southern part of Kalimantan, and southern part of Sulawesi. Moreover, VHI is significantly correlated with SPI-3 which accounted for 58% of the total area of Indonesia. It implies that the deficit of rainfall during three months has a significant impact on agricultural drought in Indonesia. In other words the agricultural drought is seen about 3-month behind the occurrence of meteorological drought. Therefore, SPI-3 and VHI clearly explain the relationship between meteorological drought and agricultural drought in Indonesia.

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