Dynamics of the Standardized Precipitation Evapotranspiration Index (SPEI) of an oil palm plantation area in Jambi province, Indonesia

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Abstract. Oil palm is susceptible to drought. Research to increase oil palm production continues to be developed, including the influence of drought to oil palm production. One of the methods used to analyze drought is using the Standardized Precipitation Evapotranspiration Index (SPEI). The purpose of this study is to analyze the dynamics of SPEI at diurnal, ten days periods, and monthly time scales, and their correlation with meteorological factors at an oil palm plantation in Jambi province, Indonesia for the year 2015. Using diurnal values, the SPEI does not indicate any drought as there are no values lower than -1. Using ten days periods, the SPEI shows a dry period starting from mid May to mid October. Using monthly values, the SPEI shows drought conditions with the driest month in October with SPEI reaching -2. Solar radiation and evapotranspiration are significantly correlated with the dynamics of diurnal index SPEI while precipitation affects significantly the dynamics of the SPEI at ten day and monthly periods.

1. Introduction

Oil palm is one of the plantation cash crops that is susceptible to drought stress, mainly due to its shallow root structure [1, 2, 3, 4, 5]. The intolerance of oil palm to drought stress severely limits growth and production [3,4]. The impact of drought on growth and production of oil palm depends on the level of drought [1]. Over the last decades, drought in South East Asia, where most of the global oil palm plantation are located, has not only increased in length and intensity, but also the area affected by drought has increased [6].

Over 10 different drought indices have been developed during the twentieth century, of which the Standardized Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI) are the most widely used [7]. The PDSI is more physical based but the SPI is easy to calculate and has different timescales. This timescale characteristic of the SPI is very important to represent different kinds of droughts. The World Meteorological Organization (WMO) has recommended SPI as the standard drought index. Recently, the SPEI was generated, which relies on a similar algorithm as SPI but includes temperature to calculate potential evapotranspiration. Therefore, the SPEI combines the advantages of SPI (different timescales) and PDSI (both precipitation and temperature play a role),
and is considered to provide a more meaningful parameter to detect the impact of drought on vegetation as a consequence [7].

The objective of this study is to analyze the dynamics of the index SPEI at diurnal, ten days periods, and monthly time scales, and identify their correlation with meteorological factors at an oil palm plantation in Jambi province, Indonesia.

2. Materials and methods

2.1 Meteorological data

Micrometeorological data (radiation net, average temperature, wind speed, humidity, soil temperature, and precipitation) were measured every ten minutes in 2015 on an oil palm plantation of PT Perkebunan Nusantara VI, Jambi (1°41'35.0"S, 103°23'29.0"E, 76 m a.s.l.). PT. Perkebunan Nusantara VI is a state-owned enterprise engaged in oil palm, rubber, and tea plantations. The meteorological tower is part of the CRC 990 EFForTS project, a collaboration between the University of Göttingen, Bogor Agricultural University, University of Jambi and the University of Tadulako. Details on the tower instrumentation are found in [8]. The tower data were used to calculate diurnal and ten days period SPEI values, whereas monthly climate data (precipitation, average temperature, and net radiation) of Jambi City (meteorological station of the Indonesian Agency for Meteorology Climatology and Geophysics at Sulthan Thaha Airport station) from 2000 to 2015 were used for the monthly SPEI calculations. The calculation of SPEI value carried out using the statistical software R.3.3.3.

2.2 Calculation of the SPEI

SPEI calculation is based on Vicente-Serrano [9] with standardizing the different values of precipitation and potential evapotranspiration with log-logistic distribution. Therefore, it is necessary to know potential evapotranspiration and precipitation in diurnal, basic, and monthly time scale. Potential evapotranspiration of diurnal and ten days period time scale was estimated using the Penman-Monteith based FAO Equation [10].

\[
ETp = \frac{\Delta (Rn - G) + \rho a C_p (e_s - e_a)}{\Delta + \gamma (1 + ra)}
\]

where \(ETp\) is potential evapotranspiration\((MJ \ m^{-2} \ day^{-1})\), \(Rn\) is net radiation \((MJ \ m^{-2} \ day^{-1})\), \(G\) is soil heat flux \((MJ \ m^{-2} \ day^{-1})\), \((e_s - e_a)\) represents the vapour pressure deficit of the air (kPa), \(\rho_a\) is mean air density at constant pressure \((kg \ m^{-3})\), \(C_p\) is the specific heat of air \((1.013 \times 10^3 \ MJ \ kg^{-1} \ K^{-1})\), \(\Delta\) represents the slope of the saturation vapour pressure temperature relationship \((kPa \ K^{-1})\), \(\gamma\) is the psychrometric constant \((kPa \ K^{-1})\), and \(ra\) and \(rs\) are (bulk) surface and aerodynamic resistances\((s \ m^{-1})\).

Meanwhile, monthly evapotranspiration was estimated using the Thornthwaite method [11].

\[
ETp = 1.6 \left(\frac{10^T}{I}\right)^m
\]

where \(T\) is monthly mean temperature \((^\circ C)\), \(I\) is a heat index calculated as the sum of 12 monthly index values, \(m\) is the coefficient dependent on \(I\): \(m=6.75 \times 10^{-7} \cdot I^3 - 7.71 \times 10^{-7} \cdot I^2 + 1.79 \times 10^{-2} \cdot I + 0.492\). After potential evapotranspiration is known, the difference between precipitation \((CH)\) and potential evapotranspiration \((ETp)\) is calculated for month \(j\) according to:

\[
D_j = CH_j - ETp_j
\]

The log-logistic distribution was used for normalizing the \(D\) series to obtain the SPEI. The probability density function of a three-parameter log-logistic distributed variable is expressed as
\[ F(X) = \frac{\beta}{\alpha} \left( \frac{x - \gamma}{\alpha} \right)^{\beta - 1} \left[ 1 + \left( \frac{x - \gamma}{\alpha} \right)^{\beta} \right]^{-2} \]

where \( \alpha, \beta, \) and \( \gamma \) are scale, shape, and origin parameters respectively, for \( D \) values in the range \( (\gamma > D > \infty) \). Thus, the probability distribution function of the \( D \) series, according to the log-logistic distribution, is given by

\[ F(X) = \left[ 1 + \left( \frac{x - \gamma}{\alpha} \right)^{\beta} \right]^{-1} \]

\[ W = \sqrt{-2 \ln(P)} \quad \text{for } P \leq 0.5 \]

\[ W = \sqrt{-2 \ln(1 - P)} \quad \text{for } P > 0.5 \]

\( P \) is the probability of exceeding a determined \( D \) value, \( P = 1 - F(x) \). Then the SPEI index is obtained from the Equation

\[ SPEI = \left( W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \right) \]

The constants are \( C_0 = 2.515517, C_1 = 0.8022853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, \) and \( d_3 = 0.001308 \).

### Table 1. Drought classification based on SPEI

| SPEI Value | Drought Category          |
|------------|---------------------------|
| 0 ≤ SPEI   | Non-drought               |
| -1.0 < SPEI ≤ 0 | Mild drought             |
| -1.5 < SPEI ≤ -1.0 | Moderate drought        |
| -2.0 < SPEI ≤ -1.5 | Severe drought          |
| SPEI ≤ -2.0 | Extreme drought          |

### 3. Results and Discussion

#### 3.1 Regional Climate Characteristics

In 2015, our site at PT. Perkebunan Nusantara VI had an annual precipitation of 1930 mm with three dry months, an average air temperature of 26.9°C, and an average air humidity of 84.8%. Indonesian territory has three precipitation patterns, monsoonal, equatorial, and local [12]. Based on this classification, Jambi region has an equatorial precipitation pattern, i.e. a monthly precipitation distribution with two peak rainy seasons and most of the annual precipitation falls within the rainy season. The average monthly precipitation for the period 2000-2015 had its maximum in April and December. According to [13], the rainy season is defined by months with precipitation equal to or more than 150 mm/month and the dry season by months with less than 150 mm/month.
The suitability of a region for oil palm cultivation is classified according to Wigena [14] by four conformity classes based on meteorological conditions in the region. The first class has a very high suitability level (S1) with an average annual air temperature of 25°C–28°C, average annual precipitation of 1,700 – 2,500 mm, and with less than two dry months. The second class has an appropriate suitability (S2) with an average annual air temperature of 22°C–25°C, average annual precipitation of 1,450 – 1,700 mm, and two to three dry months. The third class has a low suitability (S3) with an average annual air temperature of 20°C–22°C, average annual precipitation of 1,250 – 1,450 mm, and three to four dry months. The four class indicated no suitability for oil palm cultivation (N) with an average annual air temperature of less than 20°C, average annual precipitation of less than 1,250 mm, and more than four dry months. Based on this condition, the Jambi region can be categorized into the appropriate suitability class (S1).

Table 2 Requirements for oil palm cultivation (Elaeis guineensis Jack)

| Growth requirement                  | S1   | S2   | S3   | N    |
|-------------------------------------|------|------|------|------|
| Average annual air temperature (°C) | 25 – 28 | 22 – 25 | 20 – 22 | < 20 |
| Average annual precipitation (mm yr⁻¹) | 1,700 – 2,500 | 1,450 – 1,700 | 1,250 – 1,450 | < 1,250 |
| Dry months period (months)          | < 2  | 2 - 3 | 3 - 4 | > 4  |

3.2 Dynamics of SPEI in Diurnal, Ten Days Period, and Monthly
The mean diurnal SPEI is derived from hourly data in 2015. In diurnal timescale, the study area did not experience dry conditions, because the SPEI never reached -1. Nevertheless, there was a clear diurnal cycle with drier conditions during midday (10:00 to 15:00 hours) compared to other times of the day (Figure. 2).
The SPEI has significant correlation (Pearson correlation) with precipitation, air temperature, and solar radiation. The diurnal SPEI is strongly negatively correlated with air temperature ($r = -0.334$, $p = 0.001$), meaning that when air temperature is high then the SPEI is low. The correlation between SPEI and radiation are $r = -0.319$ ($p = 0.001$). The correlation between SPEI diurnal values and precipitation is $r = 0.292$ ($p = 0.001$) indicating that precipitation relates to higher SPEI.

Diurnal SPEI has the highest correlation with evapotranspiration and radiation. This is due to the daily occurrence of pseudo-dryness, namely a drought caused by high evapotranspiration but water vapor has not yet formed a cloud resulting in drought. According to [15], the amount of moisture contained in air increases exponentially with rising temperatures. The increase in temperature causes a rise in saturation vapor pressure resulting in an increase in the vapor pressure deficit between the surrounding air and the surface. The rate of evaporation depends on the amount of energy available for evaporation which depends on incoming solar radiation. Solar radiation will also affect the process of opening and closing leaf stomata. According to Lambers [16] solar radiation received by the leaves will raise the temperature and stomata leaves will open. When the leaf stomata is open, plants will lose water increasing the transpiration of plants.
Figure 3 Graph of SPEI (a), precipitation (b), temperature (c), and solar radiation (d) on ten days period time scale in 2015
The value of the ten days period SPEI index was calculated based on accumulated diurnal meteorological factors over 10 days. Dry conditions in the study area with SPEI lower than -1 occurred from May to October 2015 (Fig. 3). In the first ten days period in May, the SPEI was larger than 1 indicating wet conditions. Similarly, SPEI approaches 1 in the second ten days period of July indicating wet conditions. In the third ten days period of January, the first and second ten days period of March, the third ten days period of November, and the first and second period of December are periods that have an index value above 1 indicating wet conditions.

The ten days period SPEI are correlated with precipitation, air temperature, solar radiation, and evapotranspiration. SPEI is negatively correlated with solar radiation and air temperature with $r = -0.470$ ($p = 0.004$) and $r = -0.491$ ($p = 0.002$), respectively. This indicates that the higher the value of solar precipitation, air temperature, and evapotranspiration are the lower is SPEI indicating dry conditions. SPEI has a positive correlation with precipitation ($r = 0.894$, $p = 0.001$) indicating the higher the precipitation the higher is SPEI.

During 2015, the monthly SPEI in Jambi region was below zero. This means, in general the Jambi region experienced drought in the year 2015. According to Potop et al [17] SPEI $<-1$ will increase as the time scale used in the SPEI calculation increases. So the dynamics of SPEI index of monthly time scale has index value less than -1 more often than ten days period and diurnal time scale. However, there are several months where SPEI was still close to 0, i.e. April, November, and December, indicating that in these months Jambi region is still included in the normal category. However, in July to October the SPEI is smaller than -1, even reaching in October a value of -2 which means the Jambi region experiencing a strong drought. This is related to the strong El-Nino Southern Oscillation (ENSO) event that occurred in 2015. ENSO is a large scale ocean–atmosphere oscillation that results in very dry conditions in Indonesia. The event in 2015 was the strongest ENSO since 1997/98 [18] (Santoso et al. 2017).

The monthly SPEI shows dry conditions throughout the year with extreme drought in October with SPEI reaching -2. The monthly SPEI value has the highest correlation with precipitation with $r = 0.92$ ($p = 0.001$) but has no significant correlation with air temperature and solar radiation. This is due to the
accumulated value of precipitation on a monthly basis is very influential on SPEI. Water surplus may cause an increase in SPEI. The water balance for 12 months cannot offset the precipitation deficit that occurs in certain months [17](Potop et al. 2011)

Overall, our study demonstrates the usefulness of the SPEI to analyze the dynamics drought at diurnal, ten days period, and monthly time scales for a region in Indonesia strongly influence by large scale drought events such as the ENSO 2015.

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