Assessment of the Standardized Precipitation Index (SPI) in Tegal City, Central Java, Indonesia

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Abstract. One of the adverse impacts of climate change is drought, which occurs more frequently in Tegal city, Indonesia. The application of drought index analysis is useful for drought assessment to consider adaptation and mitigation method in order to deal with climate change. By figuring out the level and duration of the drought. In order to analyze drought in the specific area, Standardized Precipitation Index (SPI) is an index to quantify the rainfall deficit for multiple timescales. In 2015, Indonesia experienced severe drought, which has not been analyzed, yet. Thus, it is important to assess a quantitative evaluation of the drought condition. The study shows that from all deficit periods, the most severe drought in duration and peak took place in 2015, with each drought index as follows: 1 month deficit or SPI-1 (-3.11) in 1985 (-2.51) in 2015, 3 month deficit or SPI-3 (-2.291) in 1995 (-1.82) in 2015, 6 month deficit or SPI-6 (-2.40) in 1997 and (-1.84) in 2015, 9 month deficit or SPI-9 (-1.12) in 2015, 12 month deficit or SPI-12 (-1.19) in 2015. The result underlines the potential that SPI exhibits in drought identification and the use of the rainfall strongly linked to drought relief policy and measure implementation in Tegal city.

1. Introduction
Indonesia, both the rainy and the dry seasons, become the causes of flood and drought in the country. Drought is a characteristic deficiency of the water availability or water supply which results in prolonged shortages in surface or groundwater. It sometimes declared after as few as fifteen days. El-Nino phenomenon affects the drought frequencies, but it is not always referred to a severe drought because there are other factors which generate drought in Indonesia. Such as land use land cover change and rainfall anomaly.

A research Pramudya et al [1] has reported about the conversion rate of wetland into settlements and other land use in Tegal city, Indonesia. It was reported that the recent wetland conversion rate-is rather high than in the last two decades. It was also reported that rainfall anomalies, tidal flooding occurrence before the 1990s, and water insufficiency for agriculture after 2000s are the factors of land use conversion in Tegal city which resulted by the major human impact on urban activities which had related to climate change. So that, the development and improvements method on meteorological and agricultural drought condition is still an interesting topic to discuss.

The Meteorology, Climatology, and Geophysics Agency in Indonesia or usually known as BMKG uses SPI (Standardized Precipitation Index) method in order to express the analyze the meteorological
drought information. Some researchers already discussed SPI and its calculating. Agnew [2] studied relationship between drought duration, McKee [3] carried out about SPI calculation method on drought frequency and drought timescale, then Tsakiris et al [4] estimated method of SPI over a geographical area and it is used for the estimation of drought, and WMO [5] an important work drought monitoring to facilitate effective decision-making. According to the World Meteorological Organization (WMO), SPI is a recommended tool to show the calculated index probability in order to record the amount of rainfall, drought negative index value, and wet positive index value. It can also be used to forecast the condition of the climate condition monitoring on a range of time by insisting on some modeling approaches.

Operationally, using an index for drought characterization serves the following purposes: drought detection and real-time monitoring [6]. Drought period estimation by the start and end of the time scale [7], drought assessment with allowing drought to determine drought levels and investigate drought responses measures [6] drought in a region represented by drought index characterization are acceptable [7]. Then, among variously interested drought index value correlating with quantitative drought impacts over geography variable scales and timescales that facilitating to communicate the information from the drought characterization.

In order to consider and evaluate the impact of the climate change using Standardized Precipitation Index (SPI) method as the evidence of climate anomaly, this study discusses the method improvements using SPI to describe meteorological and agricultural drought conditions. Also, it discusses anomaly phenomenon to predict and monitor dry season onset in deficit 1 (monthly), 3 (three monthly), 6-9 (seasonal) and 12 (annual).

2. Methodology
Rainfall observations from a specific station were used to establish SPI time series baseline and identify drought during 1983 to 2015. Future rainfall generated then examined for drought events using the SPI. Figure 1 presented annual rainfall time series in Tegal city station.

![Figure 1. Time series of precipitation for the Tegal city meteorological station (1983-2015)](image)

Table 1 shows different time scales of SPI with related effects [8,23].
Table 1. Phenomena reflected by specific-duration standardized precipitation indices (SPI) and their applications

| SPI Duration | Phenomena reflected | Application |
|--------------|---------------------|-------------|
| 1 month      | Short-term conditions | Short-term soil moisture and crop stress (especially during the growing season) |
| 3 month      | Short and medium term moisture conditions | A seasonal estimation of precipitation |
| 6 month      | Medium-term trends in precipitation | Potential for effectively showing the precipitation over distinct seasons. e.g., for California, the 6-month SPI can effectively indicate the amount of precipitation from Oct. to Mar. |
| 9 month      | Precipitation patterns over a medium time scale | If SPI9 < −1.5 then it is a good indication that substantial impacts can occur in agriculture (and possibly other sectors) |
| 12 month     | Long-term precipitation patterns | Possibly tied to stream flows, reservoir levels, and also groundwater levels |

2.1. Location of study and rainfall data

Tegal city, Indonesia has been decided as a research site. It has a total catchment area of about 39,467 km², formed by 4 sub-districts (6° 54’ S and 109° 08’ E). E. Yin [9] suggested that in order to get well-defined research objective, qualitative analysis and data collection analysis are important to be conducted. In the previous study, Pramudya Y et al. [1] used description and linear regression to identify the frequency of dry spell and wet spell as a drought indicator but there is still limited information about drought index analysis. This study is in an agricultural area of Tegal city which analyzed 30 years of daily precipitation time series data to understand the climate change by only correlating with the frequency of dry spell and wet spell and some interviewing method to the farmers, no further evaluation [1]. In decades, this research area is growing as fast as in terms of industrialization, rapid urbanization, modern road network, and new build-up areas, which in contrary agricultural activity is decreasing meanwhile settlement expansion. Sustainable development to reduce this fast rapidly urban is challenges to avoid dire consequences of ecosystem deficiency in surrounding area, pollution, forest fragmentation, land use and land cover changes. Under such circumstances, the implementation of a best-suited drought index on recorded climate outlook was deemed necessary. The rainfall data from Tegal city station (6° 87’ S and 109°12’ E, 54.0 m above sea level), was used to represent Tegal city research area. One of the reasons for this selection was due to its close proximity to the land cover and land use change phenomenon in other hand climate anomaly. The 33 years (1983-2015) data available from BMKG [10] had been subjected to homogeneity tests before perusal.

2.2. The Standardized Precipitation Index (SPI) as a drought indicator

The SPI computation in this research was following the method which proposed by McKee [3]. For the prediction of future drought events, two parts of SPI computation were carried out. SPI was computed based on the observed rainfall from BMKG [10] in the year 1983-2015 (33 years of data). Rainfall condition in Tegal city was described by using gamma probability function. This is the similar method which proposed by McKee [3] and it has also been proven in Sharma and Singh research [11,12] which studied rainfall in monsoon seasons. Then, in order to obtain the SPI value, the function will be normalized and standardized. It could be said that z-score of the distribution function to represent the deviation event from the mean of rainfall data as the SPI value.

The Standardized Precipitation Index by McKee et al. [3] is a probability index which described the representation of abnormal wetness and dryness and compares precipitation with its multiyear average. Determining the probability density function which described long time series of precipitation is the first step of SPI method. The series could be modified for much different time duration but typically...
series used for total precipitation is 1, 2, 3, 6, 9, 12, 24 months. The cumulative probability of an observed precipitation amount could be computed after determined the function of probability density. Then, inverse normal of the Gaussian function applied to the cumulative probability (mean zero and variance one) [13].

Drought monitoring could be explained by the SPI time series. Positive SPI values indicate a wetter than the typical period (accumulated precipitation is greater than median), and negative SPI values are represented dryer period with less precipitation than normal. Accumulated precipitation was corresponded by a value of zero, then the magnitude value which started from zero could be used to explain the risk management as the wet or dry event [14].

In order to analyze the drought severity, the accumulated value of SPI could be used. SPI threshold values define drought beginning and ending [8]. When SPI value is -1 or less, it means that drought occurs. Different duration of SPI reflected different phenomena [15]. SPI-1 is described short-term conditions as short as the term of soil moisture and vegetation during growing seasons. SPI-3 is described short-medium conditions, roughly approximating seasons, while the six-month SPI (SPI6) shows the precipitation across distinct seasons. When the nine months SPI (SPI9) is less than -1.5 substantial impacts occur in agriculture and other sectors, one-year SPI (SPI12) is tied to the evolution of stream flows and reservoir and groundwater levels [16].

To explore correlations of drought with the areas in Tegal city we used monthly SPIs of different duration: SPI1, SPI3, SPI6, SPI9, and SPI12. These SPI values were calculated on the basis of long-term series of monthly precipitation within 40 years (1983-2015) in Tegal city stations to describe climate conditions according to SPIs.

2.3 Case study area and data processing
The flexibility of time scale choosing is an advantage of SPI calculation. This study focused on five kinds of time scales, which are 1, 3, 6, 9 and 12 months (SPI1, SPI-3, SPI6, SPI9, SPI12). Those times have been decided because it is suitable times to describe meteorological, agricultural and hydrological drought respectively as the study purpose. The calculation of SPI values here follows the method by Asadi Z M et al [17] and demonstrated in the following steps:

First, calculate the cumulative gamma distribution, noted that gamma distribution has been used to define the function of frequency or probability density function. The formula proposed by McKee [3] is as follows:

\[ G(x_k) = \int_0^{x_k} g(x_k) dx_k = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^{x_k} x^{\alpha-1} e^{-x/\beta} dx \]  \hspace{1cm} (1)

Symbol \( \alpha \) and \( \beta \) are defined as shape parameter and as scale parameter respectively, and it is estimated by using approximation by Thorn [18]. The value for the both of them is should bigger than zero, while \( x \) is the amount of precipitation over the consecutive months \( k \) (selected time scale) in millimeter. The function \( \Gamma(\alpha) \) refers to gamma function. When \( x_k = 0 \), the cumulative gamma distribution is undefined and the in order to encounter this situation, the cumulative probability. SPI calculations also included matching the gamma probability density function into the frequency distribution of rainfall for each station. Equations proposed by McKee [3] to optimize the following estimates of \( \alpha \) and \( \beta \) values:

\[ \alpha = \frac{1}{4A} \left(1 + \left(1 + \frac{4A}{3}\right)^{1/2}\right) \]  \hspace{1cm} (2)

\[ \beta = \frac{x}{\alpha} \]  \hspace{1cm} (3)

Where:

\[ A = \ln(x) - \frac{\Sigma \ln(x)}{n} \]  \hspace{1cm} (4)
Noted that $n$ is the number of observation data for rainfall. In order to observe rainfall events for each month and the timescale for each station, the cumulative probability is found by using resulting parameters. It is explained by McKee [3] as follows:

$$ G(x_k) = \int_0^{x_k} g(x_k) \, dx_k = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^{x_k} t^{\alpha-1} e^{-x_k/\beta} \, dx_k $$

(5)

Due to undefined gamma function for $x_k = 0$, then the value of $G(x_k)$ becomes:

$$ H(x_k) = q + (1 - q) \cdot G(x_k) $$

(6)

Noted that $q$ is the amount of zero rainfall and $H(x_k)$ which refers to cumulative probability is standardized wherewith to obtain the SPI value. Lastly, to finish the calculating of SPI value, approximate conversion by Thorn [18] is believed to use.

The number of zeros rainfall data is symbolized with $m$, then the function of $q$ could be estimated with $m/n$. The cumulative probability is then transformed into a normal standard random variable $Z$, with an average value zero and a variation of 1, the value obtained $Z$ is the SPI value. Normal standard value of random variable $Z$ or SPI is accessible by using the approximation according to Abramowitz and Stegun [19] with the equation as follows:

Calculation $Z$ or SPI for $0 < H(x_k) \leq 5$

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

(7)

Where:

$$ t = \left( \ln \left( \frac{1}{H(x_k)} \right) \right)^{1/2} $$

(8)

Calculation $Z$ or SPI for $0 < H(x_k) \leq 1.0$ proposed by McKee [3]

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

(9)

Where:

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

(10)

Where, $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$.

When the values are negative, it means that rainfall is less than a medium of historical precipitation. SPI values could use to classify the drought by certain ranges. They are: (1) Mild drought is described when the rainfall values of SPI between 0 and -0.99, (2) Moderate drought has the values between -1.00 and -1.49, (3) Severe drought has defined if the values between -1.5 and -1.99 and, (4) Extreme drought is described by the values less than -2.00.

McKee et al. [3] said that SPI is a popular meteorological drought index which based on precipitation data. This assumption is also supported by the aims of an Inter-Regional Workshop on Indices and Early Warning Systems for Drought was held in December 2009, the goal is to help in determining the best “meteorological” index and then recommend that all national meteorological services use this index (Lincoln Declaration on Drought Indices, [5]). This would make comparisons in drought severity among countries in the same region, and also among regions possible. The SPI was chosen by participants as the one to use [21]. For SPI, 30 years record is required but 50 years has been recommended [13]. Currently, this index has been widely adopted for research and operational modes.
Then, the SPI value is set to zero and as such. Wet periods and dry periods are described by the values above and below zero, respectively. National Standardized Precipitation Index [22] expected for any given values of drought in SPI from the normalized average is described as standard deviations its cumulative rainfall deficit deviates. McKee [3] also explained that drought is determined to occur if the value less than zero and it is consistently observed and reaches the value of –1 or less. Besides many limitations of SPI method, the ability of SPI method in calculating the drought levels in different time scales is an important advantage. McKee’s index could be computed for any time period and typically applied in 1, 3, 6, 9 and 12 month periods due to time rainfall deficit gradually and variably affects different water resources such as groundwater. The reflect changes in different water features (such as in Tegal city) could be described by the multitude of SPI durations.

3. Result and Discussion

3.1. Study site
Tegal city, Central Java Province Indonesia has been decided as the site for this research and it lays on 6º 54’ S 109º 08’ E as shown in Figure 2.

![Figure 2. Research Site (Tegal City), Central Java Province, Indonesia. Modified from Google Earth Pro 2016 [20]](image)

3.2. Drought duration value of each deficit period (SPI 1, SPI 3, SPI 6, SPI 9, and SPI 12)
Based on the calculation of SPI drought index, it is found that the results study in all periods of severe drought deficit and in drought criteria has a tendency to drought deficit condition. Drought occurred in the year 2015 with the value of drought index respectively the period 1-month deficit or SPI-1 (-3.11) in 1985 and (-2.51) as shown in Figure 3 (a). The period of 3 month deficit or SPI-3 (-2.29) in 1997 and (-1.82) in 2015 Figure 3 (b), the period of 6 month deficit or SPI-6 (-2.40) in 1997 and (-1.84) in 2015 Figure 3 (c), the period 9 month deficit or SPI-9 (-1.12) in 2015 Figure 3 (d), the period 12 month deficit or SPI-12 (-1.19) in 2015 Figure 3 (e). So that, according to previously research by Pramudya Y et al. [1], it was proven that there are domination factors which could encourage land use conversion at Tegal city such erratic rainfall and weather anomalies, tidal flooding occurrence before the 1990s, and also water insufficiency for agriculture after 2000s, as the impact of climate change. Estimation of the SPI index described the appearance climate anomaly evidently at the research site within 33 years.
Figure 3. SPI values for Tegal city meteorological station with (a) 1-month time scale; (b) 3 month time scale; (c) 6-month time scale; (d) 9-month time scale; (e) 12-month time scale

4. Conclusion
The SPI value occurred in Tegal city has different drought characterization to each duration in all periods of severe drought deficit and in drought criteria has a tendency to drought deficit condition. Drought occurred in year 2015 with index value respectively, for SPI 1 are (-3.11) in 1985 and (-2.51) in 2015, for SPI 3 are (-2.29) in 1997 and (-1.82) in 2015, for SPI 6 are (-2.40) in 1997 and (-1.84) in 2015, for SPI 9 are (-1.12) in 2015, and for SPI 12 are (-1.19) in 2015.

By quantifying severity levels and declaring drought’s start and end, SPI assessment currently aids in an improvement to describe erratic rainfall and weather anomalies condition in Tegal city. It needed knowledge of drought index and merge to the process of decision making for farming practices with regard to consider adaptation and mitigation of climate change in the urban city.

Adjusting planting time period and selecting proper crop varieties is one strategy in coping with climate variability in an agricultural area in Tegal city. The level of farmer knowledge mainly affects the use of drought index at the farm level in the region. Drought identification and the use of the rainfall strongly linked to drought relief policy and implementation. Better knowledge of drought index enabled farmers to interpret complex situations and adopt innovations hence minimizing the
climate risk anomaly such as drought, flood and yield agricultural reduction followed by land use conversion at Tegal city.

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