

Correlation analysis of Standardized Precipitation Index (SPI) for the water debit and level of the Cisadane River during El Niño and La Niña years

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Abstract. Hydrometeorological factor causes most disaster in Indonesia, and two of them are drought and flood. This study aims to correlate Standardized Precipitation Index (SPI) 3-monthly to water debit and water level in the Cisadane River. The monthly rainfall data from Serpong and Pasar Baru rain station from 2009 to 2011 when moderate El Niño and moderate La Niña happened. The correlation analysis between debit and water level to SPI 3-monthly used rain post of Serpong to represent the condition of the upstream area and rain post of Pasar Baru to represent the condition of the downstream area. The results showed that during La Niña year, the rainfall on the upstream area of the Cisadane River influenced the increase and the decrease in water debit and water level. Meanwhile, the rainfall on the downstream area of the river has an opposite effect on the increase and the decrease of debit and water level of the Pasar Baru. On the upstream area, the correlation between rainfall and water debit is 0.8, and the correlation between rainfall and water level is also 0.8. During El Niño year, the correlation was less than 0.5.

1. Introduction

The public's need for food and other activities is highly dependent on the availability of water. One of the water sources is rain. Rainfall is water grain or ice crystal that falls out from clouds or cloud groups. If the water can reach the earth surface, it is called rain [1]. If the water does not fall to the earth surface, it is called virga [2]. In most cases, the amount of rainfall decreases due to the long dry season that affects the supply of clean water and it will make an imbalance between the needs and availability of clean water. El Niño and La Niña are one of the global climate phenomena that have been proven in several studies can give influence of the rise and fall of the number and intensity of rainfall.

The El Niño and La Niña events occurred when the Pacific Ocean and atmosphere above it changed from their usual condition for some seasons. The central and eastern tropical Pacific warming is associated with the El Niño events. While La Niña events are the opposite, associated with a sustained cooling of the same areas. El Niño which is called hot episode and La Niña which is called cold episode is located between Nino 3 (5 °N–5 °S, 150 °E–90 °W) and Nino 4 (5 °N–5 °S, 160 °E–150 °W) and Nino 3.4 (5 °N–5 °S, 180 °E–120 °W) [3]. The impact of El Niño and La Niña to Indonesia is different in each region [4]. In the case of East Java, seasonal variability of rainfall was dominantly influenced by El Niño in 1997 [5].

Meteorological drought is an early sign of drought. The method that can be used in predicting and evaluating the meteorological drought is the Standardized Precipitation Index (SPI), developed by McKee et al. (1993) [6]. The SPI is the index used to determine the deviation of rainfall to its normal



in a long period. The SPI values are calculated using the probabilistic statistical method of the gamma distribution. El Niño in 2009/2010 and La Niña in 2010/2011 are categorized as moderate scale due to the Oceanic Niño Index (ONI) was already 0.5 in July 2009 and 0.8 in July 2010. This study aims to determine the SPI values on the upstream and downstream of the Cisadane River during the 2009/2010 El Niño and 2010/2011 La Niña. Also, this study also aims to determine its effect on the water debit and water level of the Cisadane River

2. Materials and Methods

2.1. Data and location

The data used in this study were obtained from two data sources, namely:

- Monthly rainfall data of the Pasar Baru and Serpong rain station from July 2009 to April 2011.
- Data of debit and water level of the Cisadane River from July 2009 to April 2011.

The location of this study is in the Tangerang district (106° 20'–106° 43' E and 6° 00'–6° 20' S). Debit data of Pasar Baru and Serpong from 2009 to 2011 were obtained from the Cisadane Major River Basin Organization. Data of rainfall and debit used the same time series to provide results that can represent the characteristics of the region.

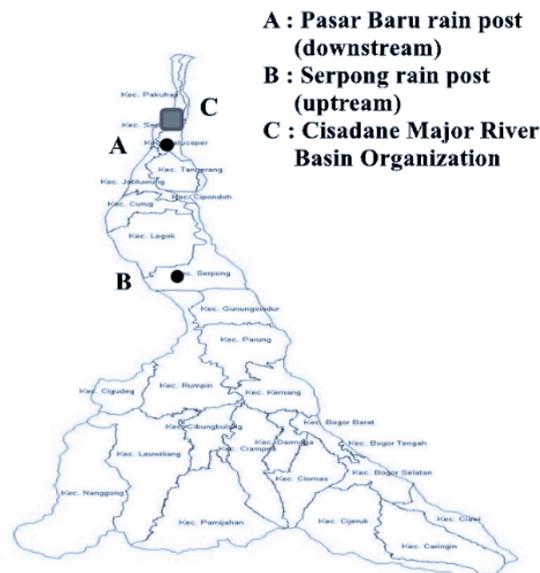


Figure 1. Map of Cisadane River flow [9].

2.2. Analysis method

2.2.1. 3-Monthly SPI. In this research, three-monthly SPI is used to give the comparison of rainfall for three months period with total rainfall from three months of the same period for all year of historical data (database). Three-monthly SPI can be used to identify short and medium drought. The three-monthly SPI is used to investigate how significant the influence of rain that occurred two months before the drought. So the influence of rainfall that occurs still have an impact to identify hydrological drought. The SPI index value is obtained from the following equation:

$$G(x) = \int_0^x g(x) dx = \frac{1}{\beta \hat{\alpha} \Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1} e^{-x/\beta} dx \quad (1)$$

where, $\alpha > 0$ is form parameter, $\beta > 0$ is scale parameter, $x > 0$ is total precipitation, and $\Gamma(\alpha)$ is Gamma function. An estimation of the coefficient values of α and β for each rain is defined by the following equation.

$$\hat{\alpha} = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right) \quad (2)$$

$$\hat{\beta} = \frac{\hat{x}}{\hat{\alpha}} \quad (3)$$

where,

$$A = \ln(\hat{x}) - \frac{\sum \ln(x)}{n} \quad (4)$$

The gamma function is not defined as $x = 0$, and since the rainfall distribution can be zero, the value of $g(x)$ becomes:

$$H(x) = q + (1 - q)G(x) \quad (5)$$

where, q is no-precipitation probability (number of zero rain events) and $H(x)$ is cumulative probability of precipitation. The gamma distribution $[G(x)]$, then turns to normal standard with zero average and standard deviation of 1, so we get the SPI index using the formula below:

$$Z = SPI = -t - \left(\frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^2} \right), \quad \text{for } 0 < H(x) \leq 0.5 \quad (6)$$

$$Z = SPI = +t - \left(\frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^2} \right), \quad \text{for } 0.5 < H(x) < 1.0 \quad (7)$$

where,

$$t = \sqrt{\ln \left(\frac{1}{(H(x))^2} \right)}, \quad \text{for } 0 < H(x) \leq 0.5 \quad (8)$$

$$t = \sqrt{\ln \left(\frac{1}{(1.0 - H(x))^2} \right)} \quad \text{For } 0.5 < H(x) < 1.0 \quad (9)$$

where x is rainfall (mm) and $H(x)$ is the cumulative probability of observed rainfall, and $C_0, C_1, C_2, d_0, d_1, d_2$ are constants with the following values:

$$\begin{aligned} C_0 &= 2,515517, & C_1 &= 0.802853, & C_2 &= 0.010328 \\ d_0 &= 1.432788, & d_1 &= 0.189269, & d_2 &= 0.001308 \end{aligned}$$

2.2.2. Pearson correlation method. Pearson correlation is used to find out the correlation between two variables and to determine the strength of linear relationship between two or more variables [8]. If a variable has the same pattern with another variable, then the two variables have a high correlation. For example, a variable has increased value and on other variables also occur the same thing than the two variables have a positive correlation. However, if there is an increase in the value of a variable but other variables have decreased the value of both variables have a negative correlation. If there is no change in a variable, although other variables change, then the two variables, have no relation (uncorrelated). The correlation equation is as follows:

$$r = \frac{n \sum XY - \sum X \sum Y}{\sqrt{n \sum X^2 - (\sum X)^2} \sqrt{n \sum Y^2 - (\sum Y)^2}} \quad (10)$$

where, r is a correlation between variables X and Y , n is numbers of data, X is the independent variable, Y is the dependent variable. The dimension used to measure the degree of linear correlation (correlation) is called the coefficient correlation which is expressed by the notation " r ". The correlation value ranges from -1 to +1. The value of correlation close to 1 means that the relationship between the two variables is greater and on the contrary, closer to the number 0 the correlation is smaller.

3. Results and Discussion

3.1. Correlation between SPI and debit and water level during El Niño

Figure 2 shows that the debit of water at Pasar Baru initially around 60 m³/s. It then decreased until September 2009 and gradually rose from October 2009. Similarly, the initial SPI value is around -0.4 and then it rose until reached the peak with a value of 1.6 November 2009, and dropped significantly in December. Figure 2 showed that the pattern of SPI and debit does not always in line. The correlation between SPI of Pasar Baru and debit is 0.4. It indicates that SPI and water debit have a weak correlation. If the index shows dry during El Niño, the water debit is high.

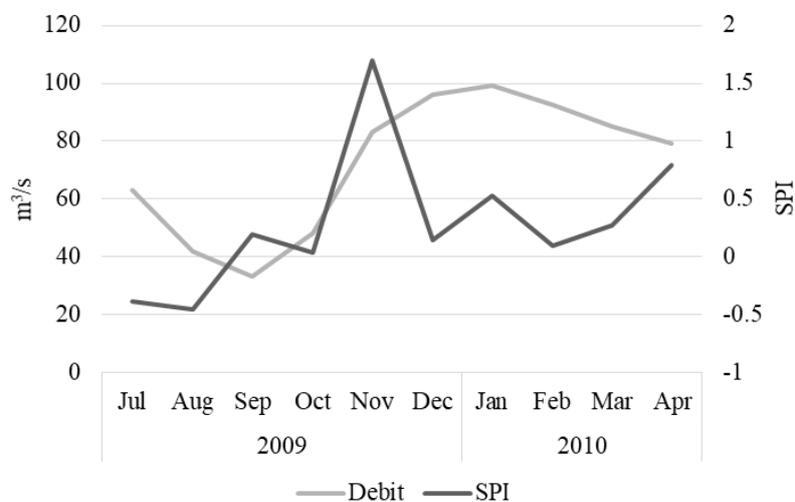


Figure 2. Correlation between the SPI Pasar Baru and three-monthly average debit during El Niño. The black line shows debit value (m³/s) and grey line denotes the SPI value.

Figure 3 shows that during El Niño the initial debit is 60 m³/s. It then dropped until September 2009 and gradually rose until reached the peak in January 2009. The variability of SPI is in line with the debit. The initial value of the SPI is around 1 then decreased until September 2009 and gradually rose until December 2009. It then dropped significantly until the end of the El Niño period. The correlation value between SPI of Serpong and water debit is 0.5.

Figure 4 shows that the SPI of Pasar Baru is -0.5. It increased gradually, reached 1.7m in November 2009 and then dropped significantly. The water level was around 1.1m, and it steadily increased, reached 1.5m in February 2010. It then decreased until the end of El Niño period. Both figures initially have the same pattern, but starting in November 2009 they do not show a good agreement. The correlation value between SPI of Pasar Baru and the water level was 0.3. It shows that the SPI in Pasar Baru does not represent water level condition during El Niño year.

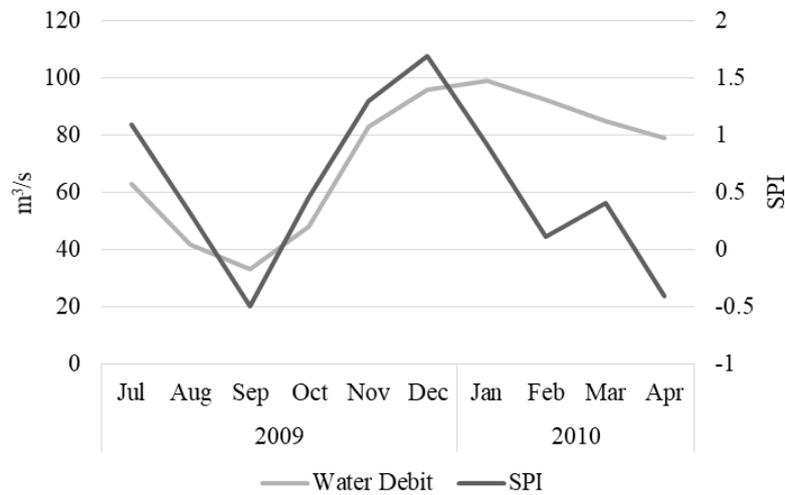


Figure 3. Correlation between SPI Serpong and three monthly average debit during El Niño. The black line shows debit value (m³/s) and grey line shows SPI value.

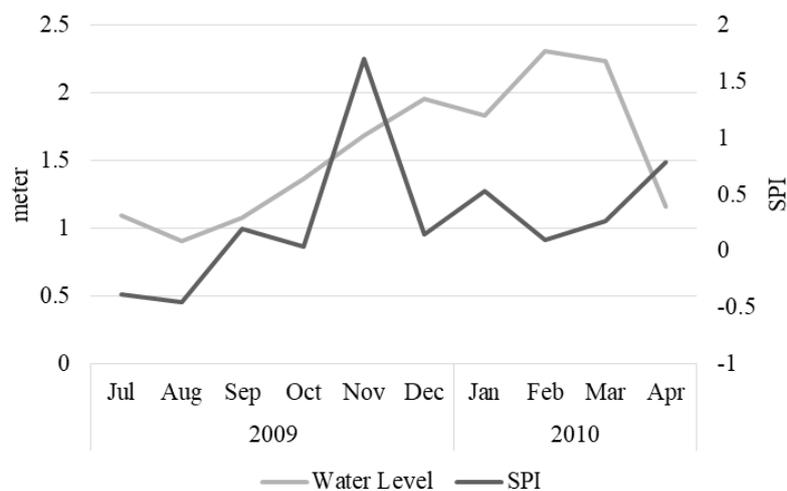


Figure 4. Correlation between SPI Pasar Baru and water level during El Niño. The black line shows SPI value and the grey line shows water level (m).

Figure 5 shows that the value of SPI Serpong was 1.2 and it decreased until September 2009 then rose until December 2009 and dropped constantly. The water level was around 1 m, and it decreased until August 2009 then rose until March 2010 and decreased again. Figure 4 shows that when SPI was dry, the water level was not always following this condition. The correlation value between SPI Serpong and the water level is 0.3.

3.2. Correlation between SPI and debit and water level during La Niña

Figure 6 shows that the water debit at Pasar Baru had the initial value of 60 m³/s. It increased until November 2010 and gradually dropped until the end of the La Niña period. In contrast, SPI which started at around 0.3 decreased until September 2010 and rose from October 2010 until April 2011. It was likely that the temporal variability of water debit in Pasar Baru does not follow the SPI pattern. The correlation value between SPI of Pasar Baru and water debit during La Niña was -0.5.

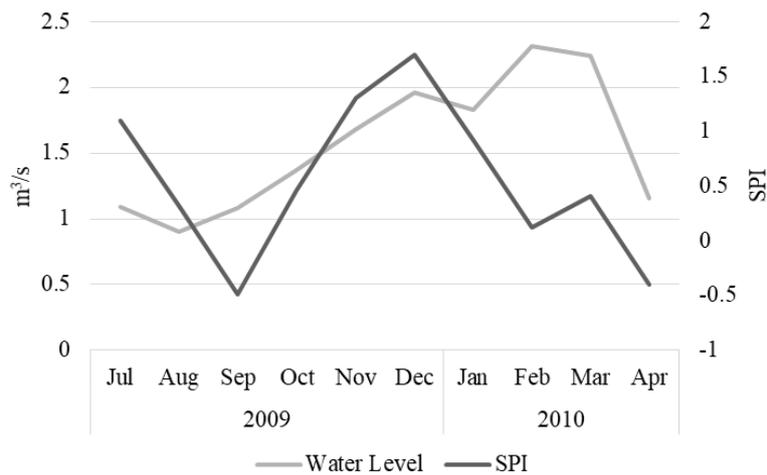


Figure 5. Correlation between SPI Serpong and water level during El Niño. The black line shows SPI value and the grey line shows water level (m).

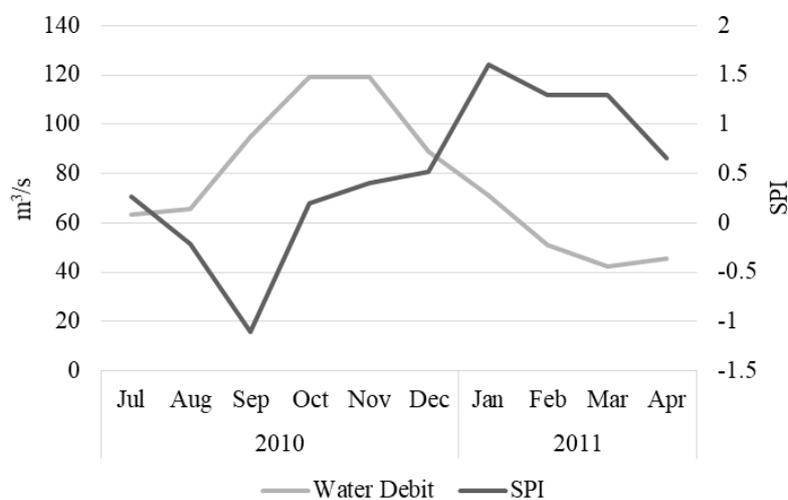


Figure 6. Correlation between SPI Pasar Baru and 3 monthly average debit (m^3/s) during La Niña. The black line shows the SPI value and the gray line is water debit (m^3/s).

Figure 7 shows that during the 2010/2011 La Niña the initial water debit was $60 \text{ m}^3/\text{s}$. It then increased until November 2010 and dropped gradually until the end of La Niña. The SPI had a similar pattern for water debit. The initial value of SPI was around 2. It dropped until the end of La Niña. Started in November 2010, the SPI dropped significantly. A good agreement between SPI and water debit suggested that when the SPI value increased, the debit would increase as well. When the SPI value decreased, the water debit dropped. The correlation value of both variables was 0.8.

Figure 8 shows that the SPI of Pasar Baru, had the initial value of 0.3. It decreased until September 2010 and then increased gradually until the end of the La Niña period and reached the peak at 1.5 in January 2011. As for the water level which had initial value of 1.5 meters increased until September 2010 then dropped gradually until the end of the La Niña period. Both graphs had a converse pattern. The correlation value of both variables was -0.9.

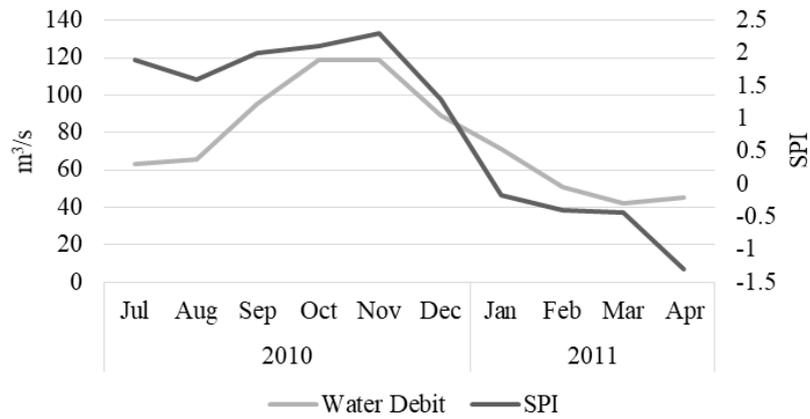


Figure 7. Correlation between SPI Serpong and 3 monthly average debit (m³/s) during La Niña. The black line shows the SPI value and the gray line is water debit (m³/s).

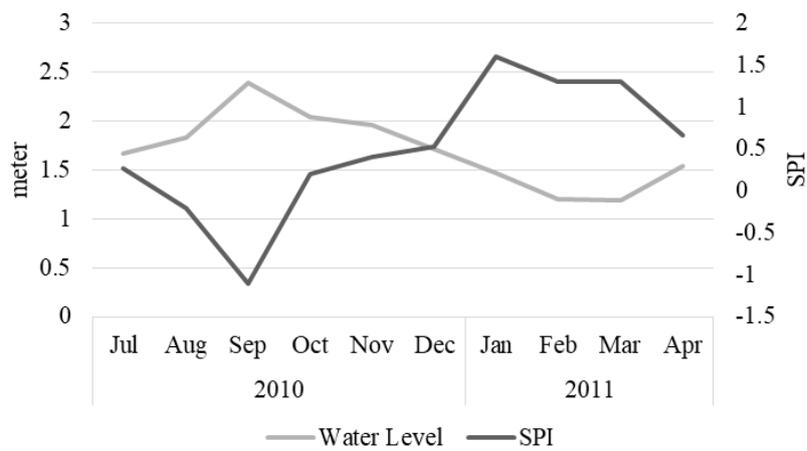


Figure 8. Correlation of SPI Pasar Baru and water level at the time of La Niña. The black line shows SPI value and the grey line shows water level in meter.

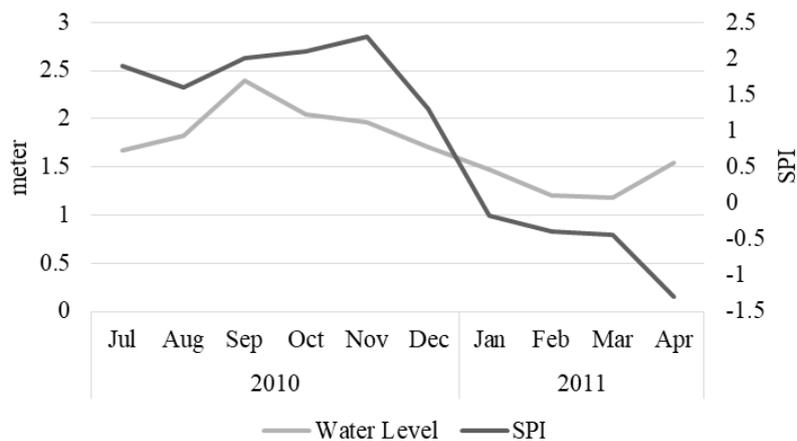


Figure 9. Correlation of SPI Serpong and water level at the time of La Niña. The black line shows SPI value and the grey line shows water level in meter.

Figure 9 shows that SPI of Serpong had the initial value of 2. It increased until reached the peak in November 2010 then dropped significantly until the end of La Niña period. Similarly, for water level which had the initial value of 1.7 meters increased on September 2010 and then dropped until the end of La Niña period. Both graphs had similar curve pattern but had slightly different of steepness. The correlation value of both variables was 0.8. It illustrated as SPI rose, the water level rose as well, so did when SPI dropped, its debit dropped as well.

4. Conclusion

During the El Niño year, the SPI does not have a high correlation to water debit and water level. However, during La Niña year, the SPI on the upstream area of the Cisadane River influences the increase and the decrease in water debit and level. While during La Niña year, the SPI on the downstream area of the Cisadane River has an opposite effect on the increase and the decrease of water debit and level. On this upstream area, the correlation between SPI and water debit is 0.8, and the correlation between SPI and water level is 0.8.

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