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Analysis of Drought Index in Sub-Urban Area Using Standard Precipitation Evapotranspiration Index (SPEI)

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Abstract: The climate change interference and increase of surface temperature have contributed to the changes at the atmosphere that give a significant effect to the availability of water. Malaysia is one of the countries which effected with this event and had been suffered series of drought events in 1997, 1998, and 2014. These problems contribute to the disruption of country's economic development and quality of life. The using of drought indices for analytical is important and it can estimate the drought affect hat are being experienced accurately. The Standard Precipitation Evapotranspiration Index (SPEI) is one of the methods in determination of drought indices. Thus, the objective of this paper is to determine the drought index using the Standard Precipitation Evapotranspiration Index (SPEI) for sub-urban river basin which is Pahang River basin. The rainfall and potential evapotranspiration (PET) data were obtained from Malaysian Meteorological Department (Met Malaysia) starting from 1988 until 2018 in determining the SPEI value for sub-urban river basin. RStudio software are being used to determine the value of SPEI for different timescale, which is 3, and 12-month. The significant value of SPEI for the river basin are influence by the population, topography, rainfall, and land use. Findings from this study are believed to the mitigation can be proposed to the related organization to take an action in designing, planning, and managing the water supply and to prevent the serious impact on the agricultural and country economic development as well.

Keywords: Climate change, drought, Standard Precipitation Evapotranspiration Index (SPEI), RStudio software

1. Introduction

Climate change have given a big environmental impact such as the unavailability of fresh water, rise in sea levels, crop damage, streamflow and groundwater depletion, extreme drought and flood event, and soil moisture reduction [1], [2]. Drought have become a common occurrence in many parts of the world, and they are a major disaster that required worldwide intervention. Due to the lack of definition for drought, a variety of drought identification and evaluation indexes have been developed to monitor drought such as Palmer Drought Severity Index (PDSI), Standard Precipitation Index (SPI), Standard Precipitation Evapotranspiration Index (SPEI), and Effective Drought Index (EDI). The purpose of evaluating the drought index is to estimate the status of drought at the specific of time.

Malaysia is tropical climate country and experiencing with abundant of rainfall around 2000 mm/year, however due to climate change and rapid urbanization nowadays, Malaysia had an experience a series of drought events in 1992,

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1997, 1998, 2015 and 2016. Thus, it is very important to look into this matter in order to plan the mitigation and prepare the way to reduce the effects of drought event. Previously, there were a drive to conduct a study on drought assessment in Malaysia such as the impact of drought on the vegetation health and most of drought studies were involved in urban area [3], [4]. However, there is no effort of study involved in the suburban area and this can be an opportunity to explore the drought index in a sub urban area. The objective of this paper is to conduct a drought index for the sub urban area in Malaysia and the study focuses on the Pahang River Basin, a sub-urban river basin and large area region in Malaysia. In this study, Standard Precipitation Evapotranspiration Index (SPEI) will be used to analyze the severity of potential future drought events with using the supporting software which is RStudio. The SPEI is one of method that used to calculate drought index which considering both precipitation and potential evapotranspiration (PET).

2. Methodology

2.1 Study Area and Data Acquisition

The location of Pahang River Basin is between N 2° 48' 45'' and N 3° 40' 24'' latitude and between E 101° 16' 31'' and E 103° 29' 34'' longitude [5] . The basin lies in the eastern part of Malaysian Peninsula. The drainage area is 29,300 km^2 which is 27,000 km^2 lies within Pahang and 2300 km^2 is in Negeri Sembilan. Sungai Pahang is the longest river in Peninsular Malaysia, 435 km long and the Pahang River Basin has an annual rainfall of 2136 – 2170 mm, a large proportion occurs during the North-East Monsoon between mid-October and mid-January [5], [6]. Fig. 1 shows the map of Pahang River Basin [7].

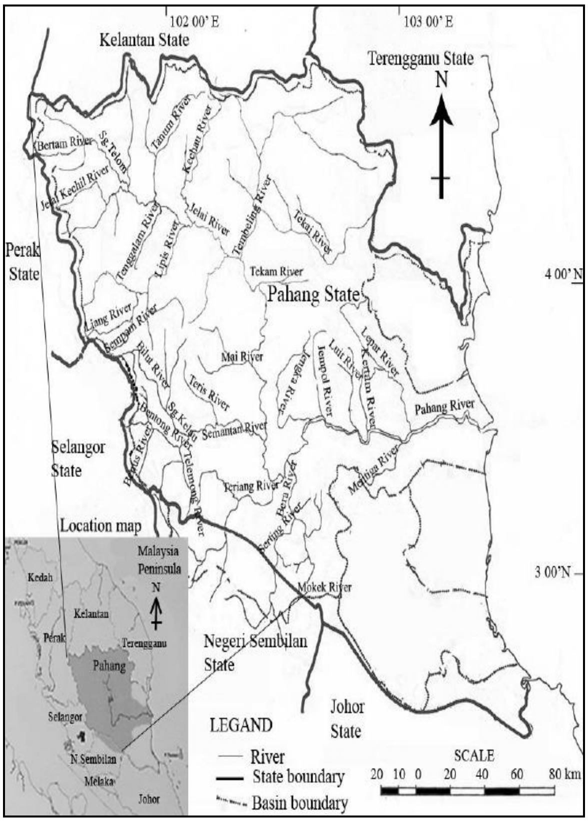

Fig. 1 - Map of Pahang

The rainfall data were collected based on selected station for Pahang River basin (see Table 1 which is obtained from Department of Irrigation and Drainage (DID) and Malaysia Meteorological Department (Met Malaysia). The data covers the period of 30 years (starting 1988-2020) based on complete data.

2.2 Standard Precipitation Evapotranspiration Index (SPEI)

Standard Precipitation and Evapotranspiration Index (SPEI) is one of the suitable indexes for researching and monitoring drought conditions, and there already have some studies that are conducting on the SPEI drought analysis [8]. The SPEI is a combining and the improvement of two indexes which is SPI and PDSI. Precipitation, temperature and evapotranspiration data are being considered in analysis of evolutionary stages of drought [9]. The computed value and classification for SPEI can be categorised as shown in Table 2

Table 1 - The location of station

Station	Latitude	Longitude
Ladang Karmen	3° 20’ 20’’	102° 24’ 50’’
Kg. Batu Cek Mek	3° 19’ 40’’	102° 30’ 25’’
Kg. Kuala Bera	3° 23’ 25’’	102° 32’ 00’’
Temerloh (Lubuk Pasu)	3° 25’ 48’’	102° 25’ 12’’
Est. Kg. Awah	3° 30’ 00’’	102° 32’ 25’’
Paya Membang	3° 27’ 15’’	103° 02’ 25’’
Kg. Serambi	3° 29’ 50’’	103° 08’ 20’’
Paloh Inai (Serambi)	3° 28’ 48’’	103° 07’ 48’’
Permatang Pauh	3° 28’ 10’’	103° 23’ 00’’
Pekan	3° 29’ 24’’	103° 24’ 36’’
Empangan Repas	3° 33’ 36’’	101° 52’ 48’’
Lubok Paku	3° 31’ 10’’	102° 46’ 40’’
Kg. Temai Hilir	3° 32’ 10’’	103° 14’ 50’’
Rumah Pam Pahang Tua di Pekan	3° 33’ 40’’	103° 21’ 25’’
Kastam Kuala Pahang	3° 32’ 00’’	103° 27’ 55’’
Kuala Krau	3° 42’ 40’’	102° 22’ 05’’
Paya Gintong di Jerantut	3° 51’ 30’’	102° 26’ 40’’
Peri Jerantut	3° 57’ 45’’	102° 25’ 40’’
Rumah Pam Paya Kangsar	3° 54’ 15’’	102° 26’ 00’’
Kg. Sg. Yap	4° 01’ 55’’	102° 19’ 30’’

Table 2 - Drought classification based on the SPEI values

SPEI Values	Drought Classification
2.00 or more	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately drought
-1.50 to -1.99	Severe drought
-2.00 or less	Extreme drought

The data of drought has been obtained from Met Malaysia and for this analysis, the SPEI monthly time scales are being consider. The calculation is based on idea of water deficit or surplus between the precipitation and evapotranspiration, based on various time scales. The computation of the SPEI can be expressed in Eq. **Error! Reference source not found.**) as follow:

$$SPEI = W - \frac{C_o + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \tag{1}$$

where $W = [-2 \ln (P)]^{0.5}$ for $P \leq 0.5$; $P = 1 - F(x)$; $C_0 = 2.515517$, $C_1 = 0.802853$, $C_2 = 0.010328$; $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$. If the value of P is greater than 0.5, then it substituted by 1-P and the sign of the final SPEI is reversed. The probability distribution $F(x)$ is calculated as presented in Eq. **Error! Reference source not found.**):

$$F(x) = \frac{1}{\left[1 + \left(\frac{\alpha}{x - \gamma}\right)^{\beta}\right]} \tag{2}$$

where α = scale, β = shape, γ = origin parameters, for D values in the range ($\gamma > D < \alpha$). They can be determined using L-moment method with Eq. **Error! Reference source not found.**) to Eq. **Error! Reference source not found.**).

$$\beta = \frac{2W_1 - W_o}{6W_1 - W_o - 6W_2} \tag{3}$$

$$\alpha = \frac{(W_o - 2W_1)\beta}{\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right)} \tag{4}$$

$$\gamma = W_o - \alpha\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right) \tag{5}$$

where Γ is the gamma function of β and W_l (l=0,1,2…) can be computed by probability weighted moments (PWMs) through the L-moment method in Eq. **Error! Reference source not found.**) as follow:

$$W_i = \frac{1}{n}\sum_{i=1}^{n} x_i \left(1-\frac{i-0.35}{n}\right)^i \tag{6}$$

where x_i is the ordered random sample ($x_1 < x_2 \ldots < x_n$) of D (D = Precipitation – Potential Evapotranspiration) and n represents the sample size. In the other way to determine the value of α, β, and γ we can use statistical curve. The value for the of α, β, and γ can be dependent on the curve data from the statistical.

2.3 RStudio Software

R program enabled the generation of SPEI timescales values for long term series for Pahang River basin. In this program the Thornthwaite equation was used which computes the monthly potential evapotranspiration (PET) [10]. The different timescales for SPEI were obtained from the data computed from precipitation and temperature. The SPEI graphs were used to categorize drought and from that, severely affected dry months and years were identified [11].

3. Results and Discussion

3.1 Standard Precipitation Evapotranspiration Index in Identification of Drought Years

The SPEI has been analysed using the values of temperature and monthly rainfall were used from years 1988 to 2020 for the Pahang River basin. The drought years were identified based on the value compute to plot the SPEI trend graphs as shown in Fig. 2 and

Fig. **3**respectively. In this study, 3-months and 12-months timescales were used in the analysis. The 3-months and 12-months value of SPEI reflected short term and long-term moisture conditions and provided a seasonal estimation of precipitation deficiency [12]. The drought years identified in this study were 1990,1991, 1997, 1998, 2003, 2005, 2007, 2009. 2010, 2013, 2014, 2015, 2016, and 2017 as shown in Fig. 2 and

Fig. **3**.

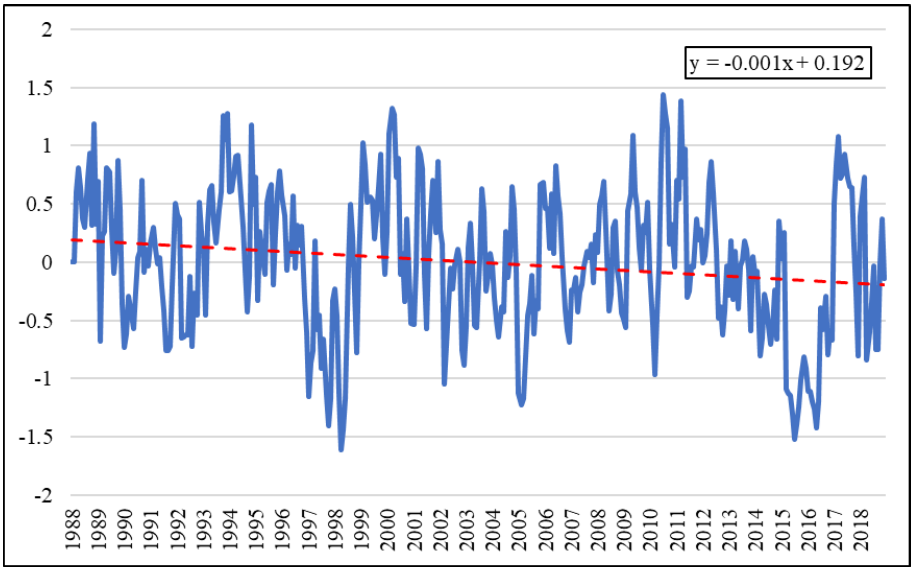

Fig. 2 - Temporal trends of SPEI 3-months lag over the study period

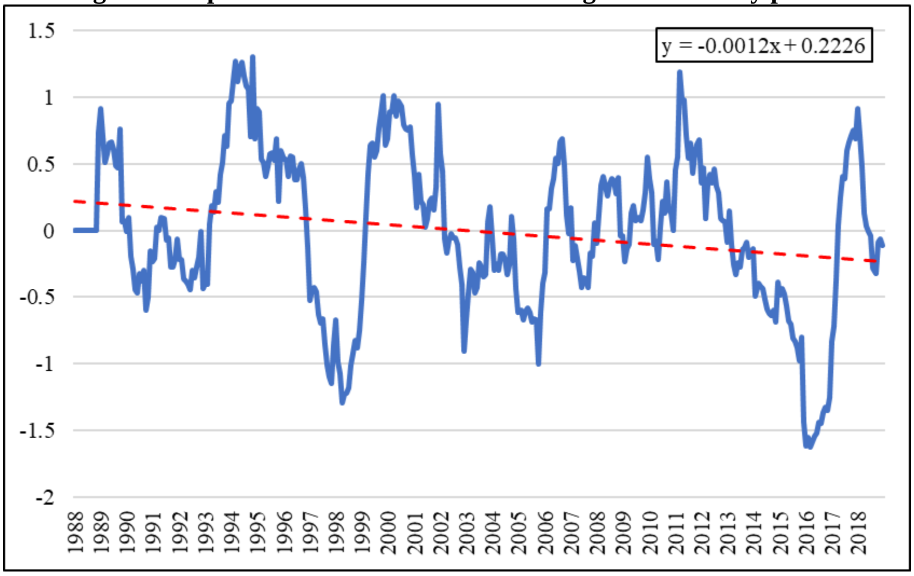

Fig. 3 - Temporal trends of SPEI 12-months lag over the study period

The sensitivity of SPEI values at different temporal scales is significantly vary with time as seen in Fig. 2 and

Fig. **3**. The seasonal drought variation is reflected in the prolonged fluctuation period of SPEI 3. The SPEI value on an annual scale is influenced by annual temperature and rainfall, therefore it can depict better river discharge. As a result, the SPEI 12 value are relatively concentrated, which may reflect to variation of inter annual drought time. The SPEI 3 can reflect changes in drought conditions over time in a short period of time, with little responsiveness to inter annual variation, but SPEI 12 clearly expresses drought on a large spatial scale. Therefore, the greater variation of SPEI value, the smaller the temporal scale. Short term of drought occurred due to extreme storage of rainfall [13] thus the SPEI value on monthly basis is influenced by changes in monthly mean temperature and rainfall which can better reflect soil water content [14]. The increasing trend of drought are shown on Fig. 2 and

Fig. **3**, which is similar to the trend from the previous study on Yellow River basin in China [15]. Although SPEI 3 and SPEI 12 showed the same trend, but the characteristic of drought was significantly different with a SPEI linear tendency rate of -0.001 and -0.0012 respectively. Furthermore, the trend do not have a fixed pattern and tend to fluctuate from time to time because of the total rainfall and temperature for a certain station are different [11].

The magnitude of drought event can be identified by using the total sum up of the negative value of SPEI of the certain years. According to the Fig. 2 and

Fig. **3**, the moderate drought event is being identified in 1997 to 1998 for SPEI 3 and SPEI 12 [11]. It covered 11 months in 1997 for SPEI 3 with a magnitude of -9.43 and October was characterized as a very dry month with a severity of -1.40. Meanwhile for SPEI 12, it covered 12 months of moderate drought with magnitude of -0.879 and the severely affected month was November with -1.14. In 1998, there were 10 months for SPEI 3 with a magnitude -7.11 and the severely affected month was May with severity of -1.44 while SPEI 12 had 12 months with magnitude of -12.02, with April being the severely affected month with the severity of -1.29. The magnitude for SPEI 3 and SPEI 12 were short and near normal with a total magnitude of -2.11 and -0.4 in the 2010. The most affected month was March for SPEI 3 and SPEI 12 with a total magnitude of -0.97 and -0.21 respectively. During 2015 and 2016 can be characterized as severe drought events as in 2015 there were 10 drought months for SPEI 3 with overall magnitude of -11.57 and July was the severely affected month and had been characterized as very dry month with the severity of -1.52. Meanwhile SPEI 12 had 12 drought months with magnitude of -9.08 and the severely affected month being December with the severity of -1.50. In 2016, SPEI 3 and SPEI 12 had 12 drought months where SPEI 3 had total magnitude of -10.60 and the month affected was May with the severity of -1.5 and as for SPEI 12, produced -17.60 of total magnitude and March was the affected month with the severity of -0.162. There are many factors that influenced the magnitude of drought such as the location of the station and the lower of annual precipitation rate [16], [17].

The frequency of drought was categorized as shown in Table 3 and being characterized as near normal, moderately, and severe drought for meteorological drought using SPEI value. According to the Table 3, 24 frequency and 16 frequencies were reported as moderate drought using SPEI 3 and SPEI 12 respectively. Meanwhile, 2 frequencies and 6 frequencies were classified as severe drought using SPEI 3 and SPEI 12 respectively. This analysis is important to extract the pattern of behavior and provides useful information on the possibility of variation thus identify the possibility of drought episode with respect to its duration and severity [18] .

Table 3 - Frequency of drought based on SPEI values for 30 years

SPEI Values	Drought Classification	Frequency	
		SPEI 3	SPEI 12
2.00 or more	Extremely wet	0	0
1.50 to 1.99	Severely wet	0	0
1.00 to 1.49	Moderately wet	15	12
-0.99 to 0.99	Near normal	331	337
-1.00 to -1.49	Moderately drought	24	16
-1.50 to -1.99	Severe drought	2	6
-2.00 or less	Extreme drought	0	0

4. Conclusion

In a nutshell, the findings indicated the SPEI could detect drought events well in terms of temporal evolution, intensity, frequency, and duration. Thus, this is one way which can help government agencies and country-based departments using drought monitoring data models as part of drought mitigation strategies in the future. Besides, the application of long-term satellite images and climate data records are recommended and become important tools for calculating drought severity levels and identifying drought prone areas in the future.

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