Drought Indices Monitoring using SPI and Z Index Score for Gua Musang, Kelantan

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Abstract. Drought has become prevalent in Malaysia due to exceptional rainfall deficit which in turn exacerbate the existing local water crisis. This paper is intended to determine the drought index in Gua Musang as one part of contribution to the development of drought index for the whole of Malaysia using the Standardized Precipitation Index (SPI) and Z score Index (ZI). The data collection used the rainfall data according to the identified station starting 2003-2015 based on the completeness of the data. The results indicated that the SPI and ZI gave quite similar result in term of condition of drought event and depicted the strong correlation between SPI and ZI. Findings from this study is believed benefit water engineers by providing information a probability distribution of water scarcity under different drought condition thus the mitigation strategy can be taken in order to address the impacts especially on water supply.

1. Introduction

Numerous human activities have led to global warming, which often came with high frequency of extreme events that are related to change in water circulation, such as drought and flood at the global scale (Leng et al., 2015). Recently, the scientist has predicted that the extreme drought event for three consecutive years starting on 2019 and the scientist have to come out with various investigations on the drought analysis and prediction such as spatial and temporal differences of drought, the mitigation of drought effects and drought prediction based on various atmospheric circulations indices (Lana et al., 2001; Huang and Chou, 2008; Cordery and McCall, 2000).

There are many methods to monitor drought that have been developed and applied over the past decade such as Standardized Precipitation Index (SPI), Standard Precipitation and Evapotranspiration Index (SPEI), Palmer Drought Severity Index (PDSI), Percent of Normal (PN), Z score, Surface Water Supply Index (SWSI) and Effective Drought Index (EDI) (Palmer, 1965; Morid et al., 2006; Yao and Ding, 1990; Mc Kee et al., 1993; Shafer and Dezman, 1982; Li et al., 2015; Khan et al., 2017; Byun and Wilhite, 1999). Detail description of the drought indices can be seen through Table 1.
Table 1. Variables use in different drought indices (Li et al., 2019; Palmer, 1965; Morid et al., 2006; Yao and Ding, 1990; Mc Kee et al., 1993; Shafer and Dezman, 1982; Li et al., 2015; Khan et al., 2017; Byun and Wilhite, 1999)

| No | Drought index                              | Variables                                    |
|----|--------------------------------------------|----------------------------------------------|
| 1  | Standardized Precipitation Index (SPI)     | Precipitation                                |
| 2  | Standard Precipitation and Evapotranspiration Index (SPEI) | Precipitation, Evapotranspiration            |
| 3  | Palmer Drought Severity Index (PDSI)       | Precipitation, Temperature, Soil Moisture    |
| 4  | Percent of Normal (PN)                     | Precipitation                                |
| 5  | Z score index (ZI)                         | Precipitation                                |
| 6  | Surface Water Supply Index (SWSI)          | Rainfall, Runoff, Snow water content, storage reservoir volume |
| 7  | Effective Drought Index (EDI)              | Precipitation                                |

Malaysia is located at tropical climate country and blessed with abundant rainfall of around 2000 mm/year (Yusof et al., 2012). However due to the climate change problem recently, Malaysia also experienced with the drought through the series of drought event in 1992, 1998 and 2015. In 1998, the drought event was associated with El-Nino and gave a huge effect from Perlis (The northern state of Peninsular Malaysia), up to the state of Negeri Sembilan and Melaka and the worst hit the Kuala Lumpur and part of Selangor during that time where water rationing had to be exercised and as a result affecting around 3.2 millions of users for about 5 months as from April to September (Nur Adawiyah et al., 2014) and it was called as national water crisis. Since then, there were a movement on the drought study in Malaysia such as assessment of drought impacts on vegetation health, a case study in Kedah by combining two types of drought assessment which are meteorological part using Standard Precipitation Index (SPI) and the agricultural part using Normalized Differentiation Vegetation Index(NDVI) (Othman et al., 2016), the usage the SWSI and SIAP software to determine occurrences of drought in Langat River Catchment (H.Khan et al., 2018) and trend analysis with respect to the drought episode according to the potential evapotranspiration based on temperature variable (Hui Mean et al., 2018). Therefore, there is an opportunity to develop drought indices which can be applied for early detection of droughts including their intensity and spatial extent. Thus, the intention of this paper is to determine the drought indices in order to contribute to the development of drought indices for the whole of Malaysia.

2. Methodology

2.1. Site Description

Kelantan is situated in northeast Peninsular Malaysia between latitudes 4° 40' to 6° 12' North and longitude 101° 20' to102° 20' East. Kelantan can be divided into several districts such as Pasir Mas, Kota Bharu, Bachok, Pasir Puteh, Machang, Tanah Merah, Tumpat, Jeli, Kuala Kerai and the largest district is Gua Musang. The annual precipitation over the area varies between 0 mm in the dry season from March to May and 1750 mm in the wet or monsoon season from November to January. Figure 1 shows the location of Kelantan and its districts.
The rainfall data were collected based on selected station for area Gua Musang as shown in Table 2 which obtained from Department of Irrigation and Drainage and Malaysia Meteorological Department. The data covers the period of 12 years (starting 2003-2015) based on complete data.

| Station     | Latitude       | Longitude       |
|-------------|----------------|-----------------|
| Brook       | 4°40' 35" N   | 101°29' 05" E  |
| Lojing      | 4°36' 00" N   | 101°24' 00" E  |
| Blau        | 4°46' 00" N   | 101°45' 25" E  |
| Ladang Mentera | 4°45' 20" N   | 102°01' 00" E  |
| Upper Chiku | 4°45’ 55” N   | 102°10’ 25” E  |
| Gunung gagau | 4°45’ 25”N    | 102°39’ 20” E  |
| Redip       | 4°49’ 00” N   | 101°59’ 00” E  |

2.2. Drought Indices Calculation

2.2.1. Standardized Precipitation Index (SPI)

Standardized Precipitation Index (SPI) was designed to identify the level of deficiency in rainfall on various time scales. It is based on the specified non exceedance probability of rainfall of certain time scale e.g weekly, monthly, yearly. In order to determine the non exceedance probability of rainfall, empirical or a theoretical, the probability distribution function is used. It generally used index among multiple drought indices to track the meteorological drought events where the less than or equal to -1 is categorized as drought spell (Palmer, 1965). The SPI can be expressed as;
SPI = \frac{\ln x - \mu_y}{\sigma_y} \tag{1}

Where \( x \) is the rainfall data, \( \mu_y \) and \( \sigma_y \) are the mean and standard deviation of \( \ln (x) \) respectively. Various drought categories are defined for different threshold values of negative SPI values e.g. -3, -2.5, -1.5, -1, -0.5 and 0 are displayed in Table 3.

### Table 3. The drought/Wetness condition according to SPI Values

| SPI Values   | Drought/Wetness condition |
|--------------|----------------------------|
| 2 and above  | Extremely wet              |
| 1.5 to 1.99  | Very wet                   |
| 1.0 to 1.49  | Moderately wet             |
| -0.99 to 0.99| Near normal                |
| -1.0 to -1.49| Moderately dry             |
| -1.5 to -1.99| Severely dry               |
| -2.0 and less| Extremely dry              |

#### 2.2.2. Z score Index (ZI)

Z score Index can be calculated by subtracting the long term mean from an individual rainfall value then divided the difference by standard deviation. The other method to determine drought index by using Z score and this method does not require adjusting the data by fitting the data to the Gamma or Pearson Type III distributions. Because of this, it is speculated that Z-Score might not represent the shorter time scales as well as the SPI (Edwards and McKee, 1997). ZI has been used in many studies. (Akhtari et al., 2009; Komuscu, 1999; Patel et al., 2007; Tsakiris and Vangelis, 2004; Dogan et al., 2012). Z-score can be calculated as follows;

\[ Z \text{- score} = \frac{X_i - \bar{X}}{\sigma} \tag{2} \]

Where \( X_i = \text{observed precipitation} \)

\( \bar{X} = \text{average value of a certain period} \)

\( \sigma = \text{standard deviation of the records} \)

Various drought conditions according to the Z score value can be seen through Table 4.
Table 4. The drought/Wetness condition according to Z score value

| Z score value | Drought/wetness condition       |
|---------------|---------------------------------|
| ≥ -2.0        | Extreme drought                 |
| -1.90 to -1.50| Severe drought                  |
| -1.49 to -1.00| Moderate drought                |
| -0.99 to 0.99 | Mild drought                    |
| ≥ 1.0         | Normal wet condition            |

3. Results and Discussions

Table 5 and 6 show the drought/wetness condition in the selected station based on SPI and ZI respectively. Most of the stations had an experience of border line between moderate wet and moderate dry for SPI and Mild drought for ZI. According to both tables, Blau indicated a condition of moderately dry with the score -1.0 to -1.49 using SPI method and Extreme Drought with the score ≥ -2.0 using ZI. Meanwhile Brook experienced of condition early normal all over the period of time since 2003 using SPI method and Mild drought using ZI method. According to the results, this showed that the ZI more sensitive to detect the onsite of drought compared to the SPI. Study conducted by Yusof et al. (2012) by using the Kriging Method indicated that the major regions of west Malaysia were subjected to an upward trend throughout the dry season, particularly eastern and western regional. This trend analysis is important tool to extract an underlying pattern of behaviour and provides useful information on the possibility of tender of variation (Yue and Wang, 2004). Other study conducted by Yusof et al. (2013) indicated the finding that there is a possible of drought episode since it is shown that the high possibility of occurrence with respect to its duration and severity.

Table 5. Drought/wetness condition according to the selected station based on SPI method

| Condition/location | Brook | Lojing | Blau | Ladang Mentera | Upper chiku | Gunung gagau | Redip |
|--------------------|-------|--------|------|----------------|-------------|--------------|-------|
| Moderately dry     |       |        | 1    |                |             |              |       |
| Near normal        | 13    | 5      | 6    | 3              | 10          | 10           | 1     |
| Moderately wet     | 8     | 6      | 10   | 2              | 2           | 12           |       |

Table 6. Drought/wetness condition according to the selected station based on ZI method

| Condition/location | Brook | Lojing | Blau | Ladang Mentera | Upper chiku | Gunung gagau | Redip |
|--------------------|-------|--------|------|----------------|-------------|--------------|-------|
| Extreme drought    |       |        | 1    |                |             |              |       |
| Severe drought     | 1     | 3      | 1    |                |             |              |       |
| Moderate drought   | 10    | 8      | 12   | 8              | 10          | 8            |       |
| Mild drought       | 1     | 2      | 1    | 5              | 3           | 3            |       |
| Normal wet condition| 1   |        |      |                |             |              |       |

Figure 2 shows a correlation between SPI and ZI and it shows a good correlation between these two indices. The correlation varies between the 0.9777 to the 0.9958 depending on the station where the
SPI generally appears more positive (or wetter) compared to the ZI which generally appears in mild drought condition. This condition has been agreed by studies of Zarei et al. (2017) and Wu et al. (2001), both of which indicated the $R^2$ value between SPI and ZI were in the range of 0.96.
4. Conclusion
Findings indicate the SPI and ZI are good tools to define, detect and monitor drought. The versatility of SPI and ZI allow for the monitoring of drought at the different time. Linear regression between ZI and SPI has a good correlation thus can be useful in monitoring and prediction of drought. Thus, it shows that study on the effects of drought is important to address the impacts especially on water supply.

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8