A REVIEW ON THE ASSESSMENT OF DROUGHT INDEX

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Abstract

The climate change interference and the increase of surface temperature have contributed towards the changes in the atmosphere that give significant effects on the availability of water. Drought is a phenomenon closely related to water quantity issues, and usually has influences on the society. This paper reviews the six available drought indices that can contribute towards the development of drought indices for Malaysia. Each index has its own variables, advantages and disadvantages. To conduct the analysis, the selection of indices should be subjected to the availability of data for that particular area. This review will benefit water engineers by providing information on the development of drought index for long term water management plans as drought management can be planned at early stage. Thus, the mitigation strategies can be devised to address the impact, especially on agriculture and water supply in Malaysia.

Keyword: climate change, drought, drought index, water management, water supply

Introduction

Climate change has tremendously altered the existing condition, resulting in the frequent extreme flood and drought events. Water is an essential element for the life of all who inhabit our planet. Drought is a phenomenon that is closely related to water quantity issues, and usually has influence on the society. Drought can be defined as a prolonged period of extremely low rainfall that results in water shortage, crop damage, streamflow and groundwater depletion, and soil moisture reduction (Yusof et al., 2012). Droughts have uncertain frequencies, durations and severities, and their occurrence is difficult to predict. There are many methods to monitor drought 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); (Mckee et al., 1993); (Morid et al., 2006); (Li et al., 2015); (M. I. Khan et al., 2017).

Determination of drought indices has been conducted in Iran where the climate condition is dry and semi-dry. This phenomenon has been observed to cause many damages to the agricultural economy and environmental landscape. Due to the impact of droughts, an investigation and assessment of drought in the Lake Urmia Basin was conducted. In the investigation, several meteorological drought indices such as Percent of Normal Precipitation Index (PNPI), Standard Index of Annual Precipitation (SIAP), Rainfall Anomaly Index (RAI), and Standardized Precipitation Index (SPI) were used to compare, evaluate, and monitor the drought events in Lake Urmia Basin in Iran. The results demonstrate that the PNPI was not an appropriate index in annual estimates, while SPI and RAI were better compared to other indices and their results are nearer to reality (Javan et al., 2016). Meanwhile in China, short- or long-term drought events were recorded in the recent years, such as the summer of 2006 event in Chongqing and Sichuan provinces (located in southwest China) which contributed to the loss of 2.5 million hectares of farmland to be harvested. Several studies were conducted to assess the drought index to be applied in other regions such as Wang et al's. (2017) which used the self-calibrating Palmer drought severity index to investigate the drought variations in China. Along the same line. Fan et al. (2018 conducted a study to determine the drought index using the SPEI to investigate the meteorological drought across China.

Malaysia is a tropical climate country and receives rainfall around 2000 mm/year. However, due to the climate change recently, Malaysia also experienced a series of drought in 1992, 1997, 1998, 2015 and 2016. In 1998, the drought event was associated with the El-Nino phenomenon that occurred for about 5 months from April to September (Nor Adawiyah et al.2015). It gave a large effect in the affected areas right from Perlis up to the states of Negeri Sembilan, Melaka and the worst hits were Kuala Lumpur and parts of Selangor. This has started a movement on the drought studies in Malaysia. Examples of the studies include 1) an assessment of drought impacts on vegetation health, a case study in Kedah , that combined two types of drought assessment: meteorological part, using Standard Precipitation Index (SPI); and agricultural part, using Normalized Differentiation Vegetation Index (NDVI) (Othman et al., 2016), 2) the usage of the SWSI and SIAP software to determine occurrences of drought in Langat River Catchment (Khan et al., 2018); and 3) trend analysis with respect to the drought episode according to the potential evapotranspiration based on temperature variable (Hui-Mean et al., 2018). These studies indicate that there is an urge to develop drought indices in Malaysia for early detection of droughts. Hence, the objective of this paper is to review the advantages and disadvantages of available drought indices which can contribute towards the development of drought indices for Malaysia.

Drought Index Assessment

Palmer Drought Severity Index (PDSI)

Palmer Drought Severity Index (PDSI) was developed to measure the supply of moisture where precipitation and temperature data are the parameters required. PDSI is more complicated than the Standardized Precipitation Index (SPI). This index ranges roughly from -4.0 to +4.0. **Table 1** shows the PDSI classification (Hayes et al., 2007).

Based on the previous studies, the PDSI method is commonly used by United Stated (U.S.) government agencies and states for the drought relief programs (Hayes et al., 2007). PDSI was the first comprehensive drought index developed in the U.S. PDSI has a benefit as it considers the fundamental effects of climate change through potential evapotranspiration (Othman et al., 2016). However, this index has many problems that are related to the calibration and spatial compatibility (Jacobi et al., 2013). Besides, PDSI values may not identify droughts as early as the other indices (Hayes et al., 2007).

Table 1 Drought classification based on the (PDSI) values (Hayes et al., 2007)

Palmer values	Drought Classifications
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderate drought
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought

Standardized Precipitation Index (SPI)

Standardized Precipitation Index (SPI) is a simple, easy, and statistically relevant measurement (Tan et al., 2015). In 1993, McKee developed this index to provide an understanding of the rainfall deficit by considering the probability of precipitation in various time scales, and the effects of drought on the availability of the different water resources. To calculate the SPI, 30 years of historical monthly precipitation data is needed. For various time scales, the SPI was established to quantify the precipitation deficit (Guenang & Mkankam Kamga, 2014). The effect of drought on the availability of different water sources can be defined based on the different time scales (Othman et al., 2016). The value of SPI can be calculated by using the equation (1) or equation (2) as follows:

$$SPI = -\left(t - \frac{c_o + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{ln\left(\frac{1}{H(x_k)^2}\right)} for\ 0 < H(x_k) < 0.5 \quad (1)$$

Or

$$SPI = \left(t - \frac{c_o + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{ln\left(\frac{1}{\left(1 - H(x_k)\right)^2}\right)} for\ 0.5 > H(x_k) < 1.0 \quad (2)$$

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. **Table 2** shows the drought classification based on the SPI values (Yusof et al., 2014).

Table 2 Drought classification based on the SPI values (Yusof et al., 2014)

SPI Values	Drought Classification
$0 \leq$ Index	Non-drought
$-1.0 <$ Index < 0	Mild drought
$-1.5 <$ Index ≤ -1.0	Moderate drought
$-2.0 <$ Index ≤ -1.5	Severe drought
Index ≤ -2.0	Extreme drought

Previous studies have established that several countries, such as China, India, Vietnam, and Malaysia are using SPI to measure the drought condition at the related areas. For example, Malaysia uses the SPI to determine the rainfall characterization (Yusof et al., 2014) and for assessing drought conditions through temporal pattern, spatial characteristic and operational accuracy indicated by SPI (Fung et al., 2020). Although the SPI is simple and easy to use, it has several disadvantages. For example, the SPI is not capable of identifying regions that may be more 'drought prone' than others. Besides, the usage of SPI at short time scales to regions of low seasonal precipitation will result in the wrong large positive or negative SPI values (Angelidis et al., 2012).

Effective Drought Index (EDI)
The EDI was developed by (Byun & Wilhite, 1999) to overcome some limitations of other indices. The EDI can do an intensive measure by considering the daily water accumulation with a weighting function for time passage. There are several advantages of EDI which is that the EDI is specifically designed to calculate daily drought severity and the calculation on the current level of available water resources is more accurate (Kim et al., 2009). The range value of EDI is from -2.5 to 2.5. The value index of -1.0 to 1.0 indicated the near normal conditions, while less than or equal to -2.0 indicated the extreme drought conditions (Salehnia et al., 2017). The value of EDI can be computed in the Equation (3) as follow:

$$EDI = \frac{DEP_j}{Std(DEP_j)} \tag{3}$$

where DEP is the deviation of the actual precipitation from its mean, Std (DEP) is standard deviation of each day's DEP, and j value is considered as 365 plus the consecutive negative value of SEP. **Table 3** show the drought classification based on EDI values (Byun et al., 2010)

Table 3 Drought classification based on the EDI values (Byun et al., 2010)

EDI Values	Drought Classification
≤ -2.0	Extreme drought
$-2.0 < \text{EDI} < -1.5$	Severe drought
$-1.5 < \text{EDI} \leq -1.0$	Moderate drought
$-1.0 < \text{EDI} \leq 1.0$	Near normal

A study has reported that The EDI had been used by Seoul, Korea in comparison to the SPI for drought monitoring data over a 200-year period. While using the EDI, it was found that there were some disadvantages of this index. The findings indicate that the EDI underestimated the status of drought events. In addition, this index did not exactly proportionate to the actual damage due to droughts, and it was limited to indicating the severity of past droughts as a single value representing each event or year (Kim et al., 2009).

Surface Water Supply Index (SWSI)
Surface Water Supply Index (SWSI) was introduced in Colorado in the 1980s as an indicator of basin-wide water availability and the comparison of water supply between basins to assess drought severity (Shafer and Dezman, 1982). This index represents the calculated index as a spatially distributed information as shown by a study conducted in Korea (Kwon and Kim, 2006). It is calculated monthly and using the basic concept that the original SWSI was the use of no exceedance probabilities as a normalizing technique, thus, allowing the comparison of water supply availability among regions of differing variability. The original SWSI was formulated as a rescaled weighted sum of no exceedance probabilities of four hydrologic components: snowpack, precipitation, streamflow, and reservoir storage. The mathematical formulation of the SWSI is shown in Equation (4).

$$SWSI = \frac{aP_{snow}+bP_{prec}+cP_{strm}+dP_{resv}-50}{12} \tag{4}$$

Where a, b, c and d are weights for each hydrologic component; a+b+c+d = 1; Pi is the probability of no exceedance (in percent) for component I; and snow, precipitation, strm, and resv is the snowpack, precipitation, streamflow and reservoir storage hydrologic components respectively. Subtracting 50 centers the SWSI values around zero and dividing by 12 compresses the range of values between -4.17 and +4.17. The no exceedance probabilities are taken from probability distributions fitted to each hydrologic component. The snowpack and precipitation variables are generally the sums or weighted sums of data from several sites in or near the basin of interest. The streamflow and reservoir variables are the sums of observed volumes at stations with readily available data. The snowpack and reservoir data are for the first of the month, while precipitation and streamflow data are for one or more previous months, depending on the season of the year. The SWSI has subjective descriptors associated with ranges of index values as shown in **Table 4** (Shafer and Dezman, 1982).

Table 4 Drought classification based on the SWSI values (Shafer and Dezman, 1982)

SWSI value	Class
+2 or above	Abundant Supply
-2 to +2	Near Normal
-3 to -2	Moderate Drought
-4 to -3	Severe Drought
-4 or below	Extreme Drought

Percent of Normal (PN)

The Percent of Normal (PN) was introduced by (Willeke et al. 1994) with the concept based on the ratio of the real rainfall to the normal rainfall and calculated for the different time scales (monthly, seasonally, and yearly). The PN was developed for characterizing meteorological drought severity but it can also be applied to calculate the streamflow drought severity. The method of calculation for this index is by dividing a given observation of cumulative precipitation $X_{i,j}^{k}$ related to the month j (j=1,…., 12) and timescale, k by the normal precipitation of the same period (typically the mean of a data series of at least 30 years). The main strong point of the PN index is simplicity and it can be considered quite effective for comparing a single region or season. The calculation of PN can be calculated using Equation (5) and the drought classification as shown in **Table 5**.

$$PNI = (Pi/P)*100 \tag{5}$$

Where Pi is precipitation in time increment i (mm) and P is the normal precipitation for the study period (mm)

Table 5 Drought classification based on the PN values (Willeke et al. 1994)

PN (%)	Class
PN >120	Wet
80< PN ≤ 120	Normal
40 <PN ≤ 80	Moderately Dry
20 < PN ≤ 40	Severely dry
PN <20	Extreme dry

Standard Precipitation Evapotranspiration Index (SPEI)

The Standard Precipitation Evapotranspiration Index (SPEI) can be defined as a simple multiscalar drought index. This index is a combination of precipitation and temperature data which is suitable for drought detection, monitoring, and exploring the impact of global warming which is good in the calculation of droughts and floods. Besides, this index is also one of the best ways to study the impact of climate change on drought events (Hui-Mean et al., 2018) and it is an alternative to SPI in quantifying the irregularities in accumulated climatic water balance (Alam et al., 2017). The SPEI calculation can be done based on Equation (6).

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \quad (6)$$

where

$W = [-2\ln(P)]^{0.5}$ $for\ P \leq .5; P = 1 - F(x);$ $C_0 = 2.515517, C_1 = 0.802853,$ $C_2 = 0.010328;$ $d_1 = 1.432788, d_2 = 0.189269$ and $d_3 = 0.001308.$

Table 6 shows the classification for every SPEI value. The previous study used SPEI to analyze the applicability of different meteorological indicators for the assessment of agricultural and forestry droughts in Europe. The researcher concluded that the SPEI had better results compared to other drought indices (Bezdan et al., 2019).

Table 6 Drought classification based on the (SPEI) values (Bezdan et al., 2019)

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

Summary of Drought Availability

The selection of the index should be reflected on the method, advantages and disadvantages, and variables. The variable is important to determine the availability of the data before the analysis can be conducted. Therefore, the analysis of the index does not solely depend on the type of index. Most importantly, it depends on the availability of data and method to analyze whether it is complicated, moderate or easy. **Table 7** shows the summary of available drought index based on method, advantages, disadvantages, and variables.

Table 7 Summary of available drought

No	Indices	Variable	Method	Advantages	Disadvantages
1	SPI	Precipitation	Calculated from the long-term record of precipitation in each location (at least 30 years). The data will be fitted to normal distribution and be normalized to a flexible multiple time scale	It can specify for each location and well suited for risk management thus can provide early warning of drought and its severity.	The data can be changed from the long-term precipitation record.
2	SPEI	Precipitation, Evaporation	SPEI is similar to the SPI, but it	Combine multi timescales aspects of the	More data requirements than the

			incorporates temperature data for the calculation of potential evapotranspiration	SPI with the information about evaporation making it more useful for climate change studies.	precipitation SPI including calculate potential evapotranspiration (PET). Long base period (30-50 years) variable should be used.
3	PDSI	Precipitation, Temperature, Soil Moisture	PDSI calculated from precipitation, temperature, and soil moisture data. Soil moisture data has been calibrated to the homogeneous climate zone. PDSI has an inherent time scale of 9 months.	Widely used to trigger agricultural drought and can be used to identify the abnormality of drought in a region.	Lag in the detection of drought over several months because the data depend on soil moisture and its properties which have been simplified to one value in each climate division. The PDSI will not present accurate results during winter and spring and tends to underestimate runoff conditions
4	EDI	Precipitation	Represent the valid accumulations of precipitation and precipitation level for a day	EDI is able to detect a short-term drought that cannot be detected by SPI. EDI detects extreme long-term droughts that are detected only by the 24-month SPI. EDI able to calculate single value	EDI underestimates the status of the drought and not exactly proportionate to the actual damage due to drought.
5	SWSI	Rainfall, Runoff, Snow water content storage reservoir volume	SWSI is used for frequency analysis to normalize long term data such as precipitation, snowpack, stream flow and reservoir level	The SWSI is very useful for indicating snowpack conditions in mountain areas to measure the water supplied for a community	The index of different basins cannot be compared with each other and has been computed seasonally.
6	PN	Precipitation	PN detected the drought by calculating the actual precipitation divided by normal precipitation, typically a 30 year mean and multiplying it by 100% for each location. Data are not normalized	PN is a simple method and effective in single region or season	Cannot determine the frequency of the departures from normal or compare with different locations and cannot identify the specific impact of drought or inhibition factor for drought risk mitigation plans.

Conclusion

Drought analysis is necessary for managing water, monitoring the dry events, mitigating the drought effect. It is also important for the planning and managing water resources systems. It is imperative to have a good selection of drought index to suit the local availability data before any analysis can be conducted. However, the application of drought legislation is more effective when the water management at the river basin level is clearly defined so that the implementation into long-term water management plans as drought management can be planned at an early stage.

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Conflict of interests

The authors hereby declare that there is no conflict of interest with any organisation or financial body in supporting this study.

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