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Drought Analysis using SPI for Selangor River Basin in Malaysia

Hazalizah bt. Hamzah[1], Hong Jer Lang[2] and Hong Kee An[3]

[1]Drainage and Irrigation Department, Malaysia
[2]Evault Technologies
[3]Hong & Associates

Abstract. Drought has affected large areas of Peninsular Malaysia and drought monitoring plays an important role in managing water resource systems in the country. In this paper, the use of standardized precipitation index(SPI) as a tool to identify and monitor drought occurrence in Selangor river basin, is presented. Long term monthly rainfall data for nine stations in the Selangor basin have been used for this study. The SPI values were computed by fitting the Gamma probability density function to the frequency distribution of the monthly rainfall records of each station for durations of 3 to 24 months. Regional drought atlas were presented for the Selangor river basin using the SPI obtained from the notable drought events occurring in 1963, 1976-77 and 1989-90.

Keywords: Drought, River Basin.

1 Introduction

Drought occurrence is a normal climate feature and drought is a gradual phenomenon. For severe cases, drought can last for many years, which can have devastating effects on agriculture and water supply. However, it is difficult to determine the onset and end of a drought. A drought can be short, lasting only a few months, or it can be persistent for years before the climatic conditions return to normal. An effective monitoring system helps to mitigate the impact of droughts. Timely monitoring of droughts can help to establish an early warning system. Evaluation of current drought condition in an area is important in mitigating the impacts of droughts of future occurrence. Drought indices are normally used to evaluate and forecast drought occurrence. A commonly used drought index is the standardized precipitation index(SPI). For this study, the SPI method has been used for drought evaluation as this method is standardized and ensures independence from geographical position as the index in question is calculated with respect to the average precipitation in the same place. This characteristic makes the SPI useful as a primary drought index because it is simple, spatially invariant in its interpretation and probabilistic nature allow it to be used in risk and decision making analysis.

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2 Materials and Methods

2.1 The Study Area

Rainfall records of the Selangor river basin were for this drought analysis. A location map of Selangor basin up to the Jabatan Kerja Raya(JKR) water intake point is shown in Figure 1. Selangor river basin up to the intake point has an area of 1450 km² and the maximum length and width of the basin are 48 km and 39 km respectively. About 30% of the basin is steep mountainous country above 600 m, 38% is in hilly country and the remainder undulating low terrain. Two-thirds of the basin is under jungle and the remainder under rubber and oil palm. Wet seasons dominate in April and May in the south west monsoon season and October to December in the north east monsoon season. Dry periods generally occur in January to March and June to September.

2.2 Rainfall Data

Rainfall data and the periods of record available are shown in Table 1. Relatively continuous data with adequate length are required for SPI calculations. Considering the continuity, the availability of concurrent records and data available from nearby stations to infill the missing records for key stations chosen, it was decided to use data to year 2000. A thorough check shows that data of nine stations listed in Table 1(marked with asterisk) were suitable for use in this study

2.3 Methodology

2.3.1 SPI Method

The SPI was developed by McKee et al., (1993).This index is based on rainfall alone making its evaluation relatively easy compared to other drought indices. SPI is also able to describe drought on multiple time scale.

Table 1. Rainfall records of Selangor basin

Station no	Station name	Period of record	Remarks
3215035*	Ladang Strathairlie	1947-1997	Gap in record due to world war II
3316028	Ldg. Sg. Gapi	1970-1993	
3416030	Ldg. Hopeful	1947-1995	Gap in record due to world war II
3315033	JKR reservoir Rawang	1951-1996	
3317004*	Genting Sempah	1974-2000	
3416026	Rasa Estate	1947-2000	Gap in record due to world war II

3416025*	Ldg Batang Kali	1950-1993	Gap due to world war II
3414029	Sg Tinggi Estate	1945-2014	Gap in record due to world war II
3414031*	Selangor Tin Dredging	1947-1995	Gap in record due to world war II
3516023*	Kuala Kubu Hospital	1947-1997	Gap due to world war II
3516022*	Loji Air Kuala Kubu	1943-2000	
3717051*	Bt Fraser	1947-2000	Gap due to world war II
3615002*	Ldg Sg Gumut	1947-2000	
3515027*	Ldg Sg Beleta	1947-1994	

The SPI is computed by fitting a probability density function to the frequency distribution of rainfall summed over the time scale of interest. The probability distribution recommended by McKee et al. (1993) and widely used elsewhere is the Gamma distribution. The calculation is performed separately for each month and for each location in space. Each probability function is then transformed to the standardized normal distribution. The Gamma distribution is defined by its frequency or probability density function as:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\alpha} \quad \text{for } x>0 \qquad (1)$$

Where $\alpha > 0$ *is* a shape factor ,β>0 is a scale factor ,and x>0 is the amount of precipitation.$\Gamma(\alpha)$ is the Gamma function which is defined as:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1}\, e^{-y} dy \qquad (2)$$

Fitting the distribution to the data requires α and β to be estimated. Edwards and Mckee(1997) suggest estimating these parameters using the approximation of Thom(1958) for maximum likelihood as follows:

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

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \qquad (4)$$

Where for n observations

$$A = ln\bar{x} - \frac{\sum \ln(x)}{n} \qquad (5)$$

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale:

$$G(x) = \int_0^{x} g(x)dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} = \int_0^{x} x^{\hat{\alpha}-1}\, e^{-x/\hat{\beta}} dx \qquad (6)$$

Substitute t for $x/\hat{\beta}$ reduces equation to incomplete Gamma function.McKee et al.(1993) used an analytical method along with suggested software code from Press et al.(1986) .Since the Gamma function is undefined for x=0 and a rainfall distribution may contain zeros ,the cumulative probability becomes:

$$H(x)=q+(1-q)G(x) \quad (7)$$

Where q is the probability of zero rainfall.

The cumulative probability H(x), is then transformed to the normal random variate, Z with mean zero and variance one, which is the value of SPI. Following Edwards and McKee (1997) the approximate conversion as an alternative is :

$$Z=SPI=-(t-\frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}) \quad \text{for } 0<H(x)<0.5 \quad (8)$$

$$Z=SPI=+(t-\frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}) \quad \text{for } 0.5<H(x)<1.0 \quad (9)$$

Where

$$t = \sqrt{\ln[\frac{1}{(H(x))^2}]} \quad \text{for } 0<H(x)<0.5 \quad (10)$$

$$t= \sqrt{\ln[\frac{1}{(1-H(x))^2}]} \quad \text{for } 0.5<x<1.0 \quad (11)$$

and

$c_0 = 2.515517$ $c_1 = 0.802853$ $c_2 = 0.010308$

$d_1 = 1.432788$ $d_2 = 0.189269$ $d_3 = 0.001308$

McKee et al. (1993) used the classification system shown in the SPI value table (Table 2) to define drought intensities resulting from the SPI. They also define the criteria for a drought event for any of the time scale. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and an intensity for each month that the event continues.

Table 2. Drought classification based on SPI

SPI values	Class
>2	Extremely wet
1.5-1.99	Very wet
1.0-1.49	Moderately wet
-0.99-0.99	Near normal
-1—1.49	Moderately dry
-1.5—1.99	Severely dry
< -2	Extremely dry

In this study the SPI-SL-6 program of World Meteorological Organization (2012) was used to compute the time series of drought indices (SPI) for each station and each month of the year at different time scales.

3 Results and Discussions

The SPI were calculated for the nine selected stations for 4 durations, namely 3 months (SPI-3), 6 months(SPI-6), 12 months (SPI-12) and 24 months (SPI-24). Examination of the SPI results indicate that station 3416025 generally experienced more severe droughts than the other stations. Short term droughts occurred in 1963, 1976 and 1990 and long term droughts were recorded in 1976-77 ,1989-90. Table 3 is a list of notable regional drought events recorded in the river basin.

Table 3. Notable drought events for Selangor basin

Period ending	Duration months	SPI for station									
		3717051	3516023	3615002	3215035	3315032	3317004	3416025	3515027	3414031	Mean
Apr-63	3	-0.61	-3.17	-1.03	-2.83	-2.96	-2.3	-2.53	-1.84	-1.63	-2.1
Sep-77	3	-2.61	-0.82	-0.99	1.04	-2.92	-1.65	-2.74	-0.62	-2.36	-1.52
Jan-90	3	-1.3	-1.47	-1.79	-1.26	0	-1.2	-1.23	-1.67	-2.01	-1.33
Apr-77	6	-1.83	-1.19	-1.53	-0.34	-0.22	-0.72	-2.49	-1.81	-1.41	-1.28
Apr-90	6	-1.26	-1.92	-3.33	-1.12	-0.73	-0.07	-2.19	-1.82	-2.33	-1.64
Aug-77	12	-2.11	-0.6	-0.74	-0.25	-0.99	-1.59	-1.93	-1.46	-1.62	-1.25
Nov-90	12	-1.13	-1.41	-1.93	-1.43	-2.46	-0.85	-4.51	-1.49	-1.49	-1.86
Apr-77	24	-2.24	-0.92	-2.03	-0.52	-1.56	-2.02	-1.07	-1.85	-0.44	-1.41
Sep-90	24	-0.53	-1.34	-2.18	-2.05	-0.99	-0.8	-2.77	-1.81	-2.05	-1.59

On a regional basis, short term droughts of 3 months are recorded in 1963. Long term droughts greater than 12 months occurred in 1989-90. Severe droughts generally occurred in the central and southern part of the basin. These drought atlas will be helpful in evaluation the current and future drought events for water managers.

4 Conclusions

The historical drought events of Selangor river basin were identified and evaluated using the rainfall records and the standardized precipitation index computed. Results obtained are useful in helping the monitoring of the current drought situation and planning and management of the water resource system in the future.

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