Evaluation of wet indices using standard precipitation index: A case study of Terengganu states

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Abstract. In line with the current climate conditions, the study of prolonged precipitation is imperative as it may predict the flood events in the future. In 2014, Terengganu is amongst the state in Peninsular Malaysia was affected by floods and it experienced three waves of floods during the monsoon seasons. In this research study, Standard Precipitation Index (SPI) is used to analyse the monthly precipitation data for two selected rain gauge stations in Terengganu over the period of forty-five years from 1970 to 2014. The objective of this study is to monitor the extreme wet conditions that eventually could cause the occurrence of floods. Comparisons were made using 3-month, 6-month, 24-month and 48-month time scales. SPI time series is calculated from precipitation index data for two rain-gauge stations in Terengganu. The shortest of time scales of SPI indicate the condition of moisture in short and medium terms, which is then used to estimate the seasonal precipitation. The longest time scales reveal patterns of long-term precipitation before the flood events. The result clearly shows that the annual trends of the wet events for longest periods are regularly experienced in wet conditions compare to drought conditions and predicted to have a higher probability of flood disaster. SK Kuala Telemong station has recorded the highest SPI values for the wet event in the entire periods, which the shortest time scales is 3.43 and longest term of time scales closer to three (2.90) in this analysis.

1. Introduction

Flood is one of the natural hazards that contribute to the economic losses around the country [1]. A flood may be the most disastrous, yet least understood of all weather phenomena. Flood can occur in a matter of months, or it can gradually threaten an unsuspecting society over several seasons. In recent years, several studies have been carried out in evaluating and assessing multiple SPI time scales of rainfall [2-4].

Recently, Dahal [2] observed trends in a number of rainfall stations over the period 1981 to 2012 using daily data from 40 meteorological stations in central Nepal. They identified long-term time scale for drought trend analysis reveals a clear tendency toward deficit index. Shah and Khan [3, 4] claimed that for a short-term time scale of SPI were not so clear for detecting the occurrence of drought
or flood events have caused enormous fluctuations, contrasting for long-term time scales of SPI, it clearly can perceive the events of drought and floods.

Due to climate change, flooding frequently occurs and causes the wet events in the previous years. Flooding can occur due to various factors such as heavy rains, high tides of the sea, air flow obstruction in the drainage system and the problems of the shallow river. Flooding also occurs due to the water flow of unusually heavy rain caused mudslides or because of the sudden change in land use. The duration of a flood that occurred either long or quick to back flood waters recede depending on the condition of a river or the topography of the place. It can occur several hours or days to persist.

Deficits or surpluses on precipitation can be quantified at any time scales by applying the Standard Precipitation Index (SPI) that proposed by McKee [5]. Other than normalization, drier and the wetter climate that can be defined in SPI, the wet periods can also be monitored. In hydrological, the different time scales reflect some difference aspects. Traditionally, the use of the short time scale is used for agricultural activities, while for water resource management advisable to use for a long period of time scales [4]. Proved by Shah [3] analyse short-term time scale (12-months) of SPI is better in agriculture activities based on the comparison the actual drought situation with SPI method.

The objective of this study is to monitor the extreme wet conditions that eventually could cause the occurrence of floods. Comparisons were made using multiple time scales for the short-term and long-term time scale. In this paper, the structure as such: Part 2 describing where the data were collected, Part 3 is a brief explanation of the theoretical framework where the use of Standard Precipitation Index (SPI) using multiple time scale. While Part 4 shows the results graphically based on the empirical data and finally in Part 5 is a discussion on the conclusion on a comparison between short-term and long-term time scale.

2. Study area: Terengganu

Terengganu is situated in eastern Peninsular Malaysia which covers a land area of 13,035 kilometres square (5,033 sq mi). The state is bordered by Pahang in the southwest, in the northwest by Kelantan, and the east by the South China Sea. Terengganu is experiencing the effects of the Northeast Monsoon season, which is the wettest episode from November until January each year and the level of flooding that occurs is depending on the intensity and distribution of precipitation at one time in the season while June and July are the driest months with minimum precipitation. The Department of Irrigation and Drainage (DID) in Malaysia stated that the previous flooding occurred in December 2014 was the largest flooding with an average of highest daily rainfall more than 400mm amongst states in Peninsular Malaysia. Table 1 presents the geographic locations of the two stations selected. These stations are selected based on the criterion of the analysis required, such as the completed period of stations.

| Station No | Station Name   | District         | Latitude  | Longitude |
|------------|----------------|-----------------|-----------|-----------|
| 5230041    | SK Kuala Telemong | Hulu Terengganu | 05°12’N  | 103°01’E  |
| 4334094    | SK Kijal        | Kemaman         | 04°19’N  | 103°29’E  |

Due to the wide climatic difference prevailing in the province, the selected stations also represent both wetter and dries districts of Terengganu. The monthly data time series for 45 years were collected from the DID Ampang for the study. The selected stations were Kemaman and Hulu Terengganu among the districts that experienced severe flooding in 2014. Terengganu had experienced three waves of floods during the monsoon seasons. The first flood wave swept the district of Kuala Terengganu, Setiu, Besut, Hulu Terengganu, Marang and Dungun began on 16 November 2014 was due to the very high intensity of rainfall and declined steadily from 14 November 2014 to 20 November 2014.
The second flood wave occurred in Kemaman, Dungun, Marang, Hulu Terengganu, Setiu and Besut beginning from 16 December 2014, this was due to excessive rains and down continuously until 30 December 2014. This resulted in a drastic increase river water level and exacerbated by the clashing of the tide starting from 22 December to 27 December 2014. The last wave of flooding occurred twice in Kemaman and Dungun districts began on January 4, 2015 is due to heavy rain fell continuously until 8 January 2015.

3. Methodology: Standard Precipitation Index (SPI)

Computation of Standard Precipitation Index (SPI) method was developed by McKee [5] to determine the wet meteorological conditions location. There are several usages of SPI from previous researches that explained the advantages of this method. In the research by Cacciamani [6] the index based on precipitation is easily be calculated and evaluated. The drought and flood episode can be quantified at different time scales [6-8]. Several advantages are defined that it is flexible; it can be calculated for multiple time scale. Short-term time scale can give early warning of drought or flood events, while longer periods reveal patterns of long-term precipitation before the flood events. Besides, its probabilistic nature gives it historical context, which is well suited for decision-making.

The short-term time scale such as 3-month giving a comparison of the precipitation over a 3-month period with the precipitation totals from the same 3-month period for all the years included in the historical record to estimate a seasonal of precipitation. For example, at the end of January, compares the precipitation total from November-December-January and continuously the current periods are added to the historical record. In the process of calculation of the SPI at long-term time scale reflects long-term precipitation patterns. Consecutive scale times of 24-month and 48-month or upward corresponds to the past 24 and 48 consecutive months of observed precipitation totals respectively. The comparison between the short-term and long-term time scale of SPI is considered important, the short-term time scale could occur the occurrences in drought or flood events in the middle of long-term time scale that would only be visible over a long period.

According to McKee [5] he clarified the classification the SPI value for extremely wet (greater than or equal to 2.0), very wet (1.5 to 1.99), moderately wet (1.0 to 1.49), near normal (-0.99 to 0.99), moderately dry (-1.49 to -1.0), severely dry (-1.99 to -1.5) and extremely dry (greater than or equal to -2.0). In the event of more than one-month time scale are used, the amount of monthly rainfall data to be cumulative in accordance with the relevant time scale. The SPI calculation is based on the cumulative probability of a given long-term precipitation data occurring at a station. The long-term precipitation data of the station is fitted to a Gamma distribution, which is then transformed into a normal distribution.

**Figure 1.** Study areas – Terengganu State.
so that mean SPI for the station and desired period is zero [9]. This is done through a process of maximum likelihood estimation of the gamma distribution parameters, $\alpha$ and $\beta$ are obtained

$$\tilde{\alpha} = \frac{1}{4A} \left( 1 + \sqrt{1 + \frac{4d}{3}} \right) \quad \text{and} \quad \beta = \frac{\bar{x}}{\tilde{\alpha}}$$

(1)

where

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

(2)

$n$ is the number of precipitation observations and $\bar{x}$ refers to the sample mean of the data. The cumulative Gamma distribution $F(y)$ resulting from the parameters has been estimated from precipitation events for the given month and time scale for different selected stations. The multiple of time scales is a main advantage of SPI that enables temporal flexibility in the evaluation precipitation conditions.

### Table 2. Example of cumulative of SPI for 3-month.

| Month ($i$) | Year ($j$) | Monthly Precipitation Amount | Cumulative of 3-months timescale of SPI |
|-------------|------------|------------------------------|----------------------------------------|
| 1           | 1          | $X_{1,1}$                    | -                                      |
| 2           | 1          | $X_{2,1}$                    | -                                      |
| 3           | 1          | $X_{3,1}$                    | $X_{3,1} + X_{2,1} + X_{1,1}$          |
| 4           | 1          | $X_{4,1}$                    | $X_{4,1} + X_{3,1} + X_{2,1}$          |
| 5           | 1          | $X_{5,1}$                    | $X_{5,1} + X_{4,1} + X_{3,1}$          |
| ...         | ...        | ...                          | ...                                    |
| $i$         | $j$        | $X_{i,j}$                    | $X_{i-2,j} + X_{i-1,j} + Y_{i,j}$      |
| ...         | ...        | ...                          | ...                                    |
| 12          | $k$        | $X_{12,k}$                   | $X_{12,k}$ + $X_{11,k}$ + $X_{10,k}$  |

Monthly precipitation amount will be calculated according to the time required of timescales. Table 2 shows the computation of SPI for 3-month timescales. $X_{i,j}$ represents as a random variable of precipitation amount for $i$ month ($i = 1, 2, 3, \ldots, 12$) while $j$ represent year ($j = 1, 2, 3, \ldots, k$) in a station.

### 4. Result

Comparisons of 3-month, 6-month, 24-month and 48-month time scales of SPI time series values were computed. In Table 3, we present the SPI values for both short-term and long-term time scales. The result in table 3, shows the comparison for the short-term and long-term time scale for both stations. The data for comparing both time scale is selected based on the highest value from the plot of 3-month time scale. Shows, for the short-term time scale for both station is experienced extremely wet events and for long-term time scale, for SK Kuala Telemong station also facing extremely wet, and moderately wet for SK Kijal station and this indicate can occur the occurrence of the flood.

### Table 3. Comparison of short and long-term time scale.

| Station                  | Year (Month) | Short-term time scale | Long-term time scale |
|--------------------------|--------------|-----------------------|----------------------|
|                          |              | SPI-3 | SPI-6 | SPI-24 | SPI-48 |
| SK Kuala Telemong        | 2013 (February) | 2.74  | 2.05  | 2.40   | 2.90   |
| SK Kijal                 | 1984         | 2.93  | 2.44  | 1.17   | 1.02   |

The monthly time series plots in Figure 2 and 3 represent the trend for dry and wet events of the selected two rain gauge stations in Terengganu. From the trends indicated from both stations had identified significant positive and these trends are anticipated the wet condition is continuously in period
45 years from 1970 to 2014. From the graphical representation in Figure 2 and 3, surpluses and deficits trends were apparent. For longest time scales for these entire periods, for both stations were start of a time series with smaller values of SPI and higher SPI values were present at the end.

![SPI-3](image1) ![SPI-3](image2)

![SPI-6](image3) ![SPI-6](image4)

![SPI-24](image5) ![SPI-24](image6)

![SPI-48](image7) ![SPI-48](image8)

**Figure 2.** SPI calculation for Terengganu precipitation station of SK Kuala Telemong.

**Figure 3.** SPI calculation for Terengganu precipitation station of SK Kijal.

It is clear from Figure 2 that the rainfall is described by fluctuating alteration of wet and dry years in a periodic pattern. Most of the consecutive negative SPI values occurred before 1985 and whilst positive SPI values occurred successively from 2001 to end of the period. The 1983 rainfall amount was the extreme record for drought event in the observation period with SPI value exceeded the value of negative 2 ($-2.09$) and the wetter is successive in the year 2011 to 2013 with SPI value exceeded the value of positive 2 and the extreme value of SPI is 2.76 in 2012.

Similarly, Figure 2 and Figure 3 revealed the positive SPI values from 2001 to 2014, however, there are a couple of months in the period of occurrence of dry events. For both stations that faced consecutive of the wetter year may be associated with the probability of flood episodes.
5. Conclusion
This study to figure out establish the trends in precipitation for two selected station in Terengganu for the period of in period 45 years from 1970 to 2014, through the analysis conducted in by using the Standard Precipitation Index (SPI). Within respect to wet conditions analysis, exploring forecasting for shortest and longest-term timescales of the wet event is using the monthly precipitation index data that were calculated in this study. Thus, both stations indicate for the long term has to experience wet events and are expected to have a probability of flood disaster during wet events. SK Kuala Telemong station has reported the highest SPI value for a surplus of precipitation for shortest and longest of time scale amongst other stations. The 3-month (shortest) time scale is closer to 3 (2.76) in the year 2009 and for 48-month (longest) time scale was recorded with value 2.22 in 2013. Short-term revealed that short term wet conditions had enormous fluctuations for both stations throughout the period of record. However, long-term were noticeably perceived as to detecting flood periods and it can be applied in Water Resource Management.

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