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Application of the Standardized Precipitation Index (SPI) in Identifying Extreme Events

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Abstract: Extreme events such as drought and flood are the two of the most common extreme weather that take places in Malaysia. The Standardized Precipitation Index (SPI) is one of the indices used to quantify the precipitation deficit/excess for multiple timescales. The objectives of this study were to identify the historical extreme events using the SPI, to investigate the most appropriate combination of the SPI with its respective timescale and to identify the SPI trend analysis for the selected rainfall station. The data from 1978-2017 of eight (8) rainfall stations in Johor were selected for the computation of SPI. Based on the SPI values obtained, the number of wet and dry event were used in detecting the historical extreme events. It is shown that the past flood events happened in Johor in 2006 were related to the Northeast Monsoon while drought events that occurred in 1997 were related to the *El Nino* phenomenon. It is proved that the most appropriate SPI timescale was 12-month as it can be used to detect long term precipitation patterns. Lastly, the results from 12-month SPI values showed that five (5) stations had a decreasing trend while three (3) stations had an increasing trend. In conclusion, the results of this study can be used for future planning and forecasting of extreme events in Johor area.

Keywords: Standardized Precipitation Index, Mann Kendall Trend Test, Historical Extreme Events

1. Introduction

Climate change is a global issue that can lead to changes in intensity of rainfall with noticeable impacts on local hydrological processes (Labat *et al.*, 2004). Due to climate change, natural disasters such as extreme weathers, forest fire, earthquakes and tsunami occurs more frequently. Extreme weathers such as flood and drought are no longer considered as a rare occasion that happened in Malaysia. Every year, these extreme weathers has affected the economy, society and environment. Identifying these extreme events is important in order to manage water resources in our country. Johor is affected by floods during the monsoon season, particularly in the southern area. Recently, Johor also has been impacted by drought. Based on the extreme weathers that had happened in Malaysia,

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monitoring and assessing these events are crucial in managing water resources. Monitoring these events is a challenge due to the recurrent climate change. Drought forecasting is important in order to provide early warning of drought. Many indices have been developed to understand the drought and flood characteristics but there are still limited study on identifying the most appropriate index to reflect the impact of drought/floods on the availability of the different water resource.

The objectives of this study were to identify the historical extreme events using the Standardized Precipitation Index (SPI), to investigate the most appropriate combination of SPI with its respective timescale and to identify the SPI trend analysis for the selected rainfall stations. This paper is organized as follows. In section 2, a brief description on selected rainfall stations and methods used are discussed. Meanwhile, in section 3, the results of the SPI and its trend analysis were presented. Finally, in section 4, the conclusion of this study are summarized.

2. Data and Methods

Johor is one of the states in Peninsular Malaysia located in the southern region.has a humid tropical climate that blows from the South China Sea with monsoon rains from November to March. Rainfall averages in Johor were generally higher with 2,500mm of rainfall each year in the higher elevated area and most of the rainfall falls during the North-East monsoon season.

The historical precipitation data from eight (8) selected rainfall stations in Johor were collected from Department of Irrigation and Drainage (DID) and Malaysia Meteorological Department. The selected rainfall stations were Kompleks Perumahan Pontian, Ladang Getah Malaya Kota Tinggi, Ladang Paya Lang Segamat, Ladang Pekan Layang-Layang, Ladang Teluk Sengat Kota Tinggi, Bt 42 Jalan Kluang Mersing, Pintu Kawalan Sembrong Batu Pahat, and Stor JPS Johor Bahru.

2.1 In-filling Missing Data

Since these rainfall data series often contain gaps or incomplete value, the missing data from the selected rainfall stations were determined using two methods which are Arithmetic Mean Method and Normal Ratio Method. Arithmetic Mean method were used if the normal annual precipitation at the nearby gauges is less than 10% of the normal annual precipitation at the stations involved. This considers equal weights from all surrounding rain gauge stations and utilizes the arithmetic mean of precipitation data.

$$P_x = \frac{1}{m} \Sigma_{i=1}^{m} P_i \qquad \text{(Eq. 1)}$$

where P_x is the estimation of the missing value; P_i is the rainfall values of the rain gauges used for estimation and m is the number of surrounding stations. Meanwhile, Normal Ratio method were used if the normal annual precipitation of any nearby gauges is more than 10% of the gauge that is under consideration. This considers the impact of each station in the proximity (Singh,. 1994).

$$P_x = \frac{1}{m} \Sigma_{i=1}^{m} \left(\frac{N_x}{N_i} \right) P_i \qquad \text{(Eq. 2)}$$

where Px is the estimation of the missing value; Pi is the rainfall values of the rain gauges used for estimation; m is the number of surrounding stations; Nx is the mean annual precipitation of X station and Ni is the mean annual precipitation of surrounding stations.

2.2 Standardized Precipitation Index (SPI)

The computation of Standardized Precipitation Index (SPI) method was designed by McKee *et al.,* (1993). The SPI were used to identify the location of the wet meteorological conditions. Several advantages were characterized as being flexible; it can be measured on a multiple time scale (1,3,6,9, and 12 months). Short-term timescales provides early notice of drought or flood events, whereas longer periods may expose the patterns of long-term precipitation prior to flood events.

The estimation of the SPI was based on the cumulative likelihood of long-term precipitation data occurring at the station. The station's long precipitation data was lifted to the Gamma distribution, which is then converted into a normal distribution, so that the mean SPI for the station and the desired duration is zero (Edwards D C *et al.*, 1997). This was achieved by a method of calculation of the maximum likelihood probability of the gamma distribution parameters, α and β are obtained.

$$\alpha = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right) \quad \text{and} \quad \beta = \frac{x}{\alpha} \qquad \text{(Eq. 3)}$$

where ,

$$A = \ln(x) - \frac{\sum \ln(x)}{n} \qquad \text{(Eq. 4)}$$

where n is the number of precipitation observations and x is the sample mean of the data. In this study, the SPI Generator Programme version 1.7.5 were used to generated the SPI data. This programme accepts precipitation data and works with variety of timescales and data formats (weekly, monthly). It also generates SPI data as well as frequency and drought period data as options.

2.3 Mann Kendall (MK) Trend Test

The MK test used for the determination of monotonous patterns and is focused on ranks (Helsel and Hirsch, 2002). This is a measure of the similarity between a series of pairs of values. The relevance of the trend observed can be reached at various degrees of significance (generally taken as 0.05). The MK test statistics and the sign function are determined using the following formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \qquad \text{(Eq. 5)}$$

$$sign(x_j - x_i)\begin{cases} +1 & x_j > x_i \\ 0 & x_j = x_i \\ -1 & x_j < x_i \end{cases} \qquad \text{(Eq. 6)}$$

where n is the number of data and x is the data point at time i and j (j > i). The variance of S is as follows;

$$\text{var}(S) = \left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i i(i-1)(2i+5) \right] / 18 \qquad \text{(Eq. 7)}$$

where t_i is number of ties of extent i and m is the number of tied groups. For n more than 10, the standard test statistic Z is calculated as the MK test statistic as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if \ S > 0 \\ 0 & if \ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if \ S < 0 \end{cases} \quad \text{(Eq. 8)}$$

The presence of a statistically relevant trends was assessed using the Z value. Positive Z values shows increasing trends, while negative values reflect weakening trends. To test either the monotonic trend (a two-tailed test) increased or decreased at a level of significance, H0 should be excluded if $|Z| > Z_{1-a/2}$, where $Z_{1-a/2}$ is derived from the standard normal cumulative distribution tables. For instance, at the 5% significance level, the null hypothesis shall be denied if $|Z| > 1.96$. The higher magnitude of the Z value means that the trend is statistically more relevant. In this study, Mann Kendall trend test were determined using the trend analysis functions in the Minitab software. This software generates the trend of the SPI values obtained from the selected rainfall stations.

3. Results and Discussion

3.1 Identifying Historical Extreme Events By Using SPI Values

In this study, different timescale of 1 month, 3 months, 6 months, 9 months and 12 months' SPI time series were computed. The methods were applied to monthly precipitation data from 1978 to 2017. Based on the SPI values obtained, the wet events and dry events occurred were recorded. It is shown that the duration of wet events occurred increased as the timescale increased. For 1 month SPI, the span of wet events occurred ranged from 2 months to 4 months and the highest wet events occurred were for 11 months. Next, for 3 months SPI, the duration of the wet events varies from 3 months to 8 months while the highest were for 13 months. Then, for 6 months SPI, the period of wet event differed from 7 to 12 months and the longest wet event happened for 23 months. For 9 months SPI, the span of wet events happened varies from 9 months to 16 months and the longest span occurred for 23 months. Lastly, for 12 months SPI, the wet events occurred in a long span between 11 months and 23 months. The longest wet events occurred were for 28 months. Figure 1 shows the maximum occurrence of wet events obtained from the SPI computation. These stations recorded the longest duration of wet events which lasted for 23 months to 28 months.

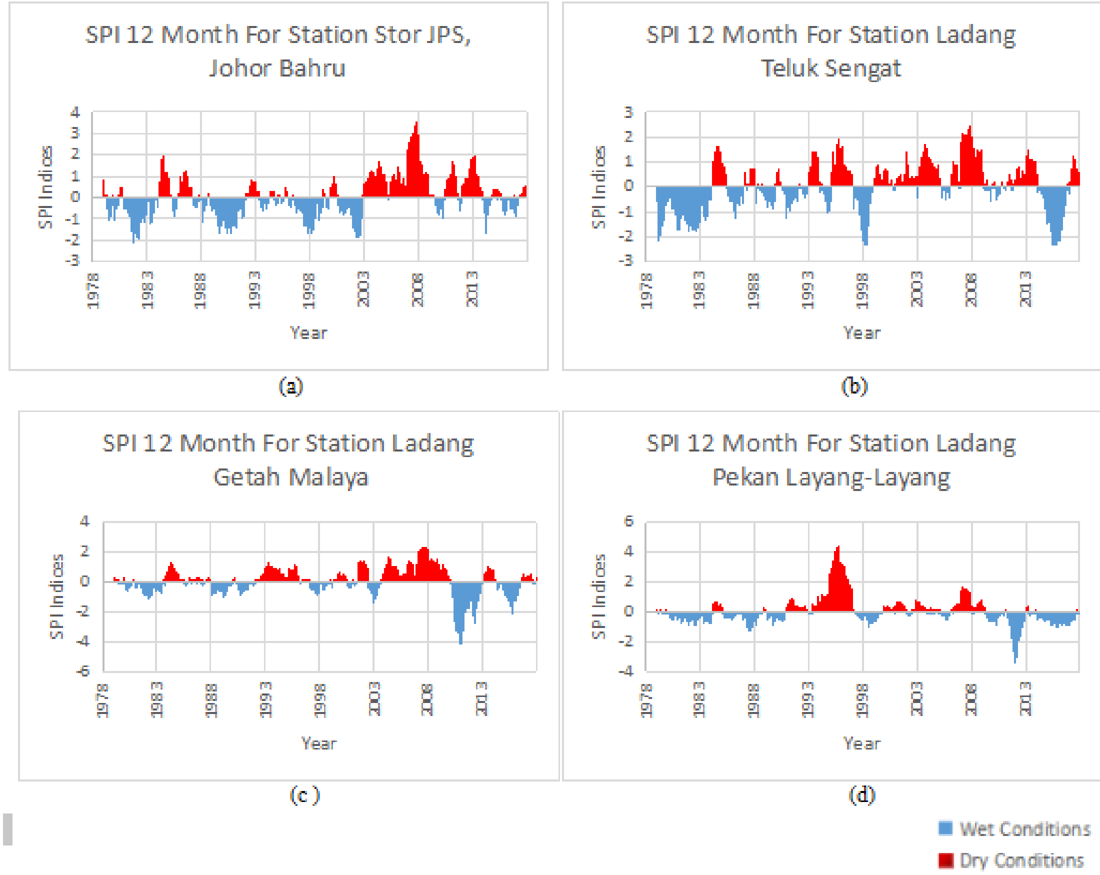

Figure 1: Stations with the longest duration of wet events

For the dry events, the span of drought for 1 month SPI were ranged between one to 6 months with the longest drought last for 10 months. For 3 months SPI, the period of dry events last for five to 10 months while the longest period of drought was for 12 months. Next, for 6 months SPI, the span of dry event was between 10 to 13 months with the most prolonged drought for 14 months. Then, for 9 months SPI, drought occurred between 10 to 20 months while the most extended period was for 21 months. Lastly, for 12 months SPI, the period of dry events recorded were between 13 to 26 months with the longest period of 29 months. Figure 2 shows the maximum occurrence of dry events obtained from the SPI computation. These stations recorded the longest period of dry events which lasted for 24 months to 29 months.

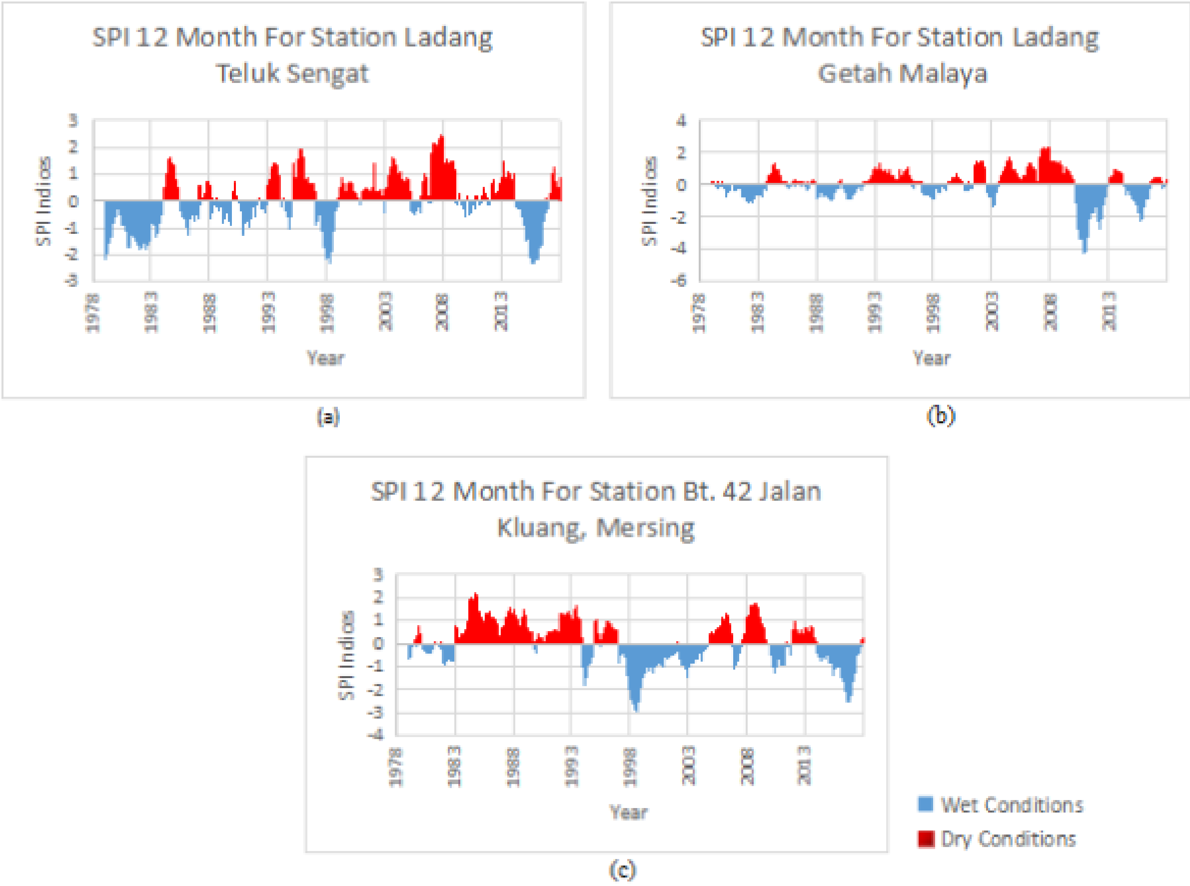

Figure 1: Stations with longest duration of dry events

From the SPI results, few flood events that had occurred might related to the historical flood from other researches. For flood events that were recorded at the end of 2006 and early 2007 such as at station Pintu Kawalan Sembrong, Stor JPS, Johor Bahru, Ladang Teluk Sengat Kota Tinggi and Ladang Getah Malaya Kota Tinggi may associate with the flood in Johor State that occurred due to the Northeast monsoon (MNRE, 2007a). Moreover, wet events that had taken place in 2008 at station Pintu Kawalan Sembrong, Stor JPS, Johor Bahru, Ladang Teluk Sengat Kota Tinggi, Ladang Getah Malaya Kota Tinggi and Bt 42 Jalan Kluang, Mersing may link to the flood in Johor State in 2008 (Chan, 2012).

Based on previous studies, the number of dry events that were recognized were not as much as wet events. The most well-known drought that had occurred in Malaysia was the *El Nino* event. This dry event had taken place from 1997 to 1998. From Table 4.3, it is recorded that most of the drought events had occurred during the *El Nino* phenomenon such as at station Ladang Paya Lang, Pintu Kawalan Sembrong, Kompleks Perumahan Pontian, Stor JPS Johor Bahru, Ladang Teluk Sengat Kota Tinggi and Bt 42 Jalan Kluang, Mersing.

3.2 Determination of the Most Appropriate SPI Timescale

The SPI was created to quantify the precipitation shortfall across several timescales or moving time periods (World Meteorological Organization, 2012). These timescales illustrate the drought's effects on various water resources which are needed to achieve the objective of this study. For 1 month SPI timescale, compares well to the percentage of normal precipitation for the month. The 1 month SPI is a short-term measure that can be useful for predicting soil and crop stress during the growing season. Next, the 3 months SPI reflects short-and medium-term moisture conditions and provides a seasonal prediction of precipitation. A relatively normal 3 months period could occur in the midst of a longer term drought were noticeable on larger time periods. By using a 3 months SPI which has a longer time scales, it prevented a misconception that any “drought” has ended.

Then, for 6 months SPI, it reflected medium-term precipitation trends and were still thought to be more responsive to conditions at this scale. A 6 months SPI were particularly useful for displaying precipitation over different seasons. For 9 months SPI indicated precipitation trends on a medium time scale. Droughts typically develop over the course of a season or more. SPI values less than -1.5 for these time scales were usually a reliable indicator that pretty severe impacts had occurred in agriculture and may showed up in other sectors as well.

Overall, the most appropriate combination of SPI with its timescale are 12 month. This is because it reflects long term precipitation patterns. Furthermore, the performance of SPI 12 months differed significantly from the performance of SPI for 1, 3, 6 and 9 months. A number of studies also have found that a 12 months SPI is more predictable than 3 months SPI (Belayneh and Adamowski 2012; Djerbouai and Souag-Gamane 2016; Zhang et al. 2017b). Lastly, since 12-month SPI represented most wet and dry historical extreme events, it is shown that 12-month SPI were the most appropriate combination of SPI with its timescale.

3.3 SPI Trend Analysis using Mann Kendall (MK) Trend Test

In order to obtain the trend of the SPI values calculated using the Mann Kendall trend test, the Z statistics values were computed according to each station. The positive Z values represent an increasing trend and vice versa. The trend analysis was determined using the 12-month SPI values. Table 1 shows the summary of the SPI trend analysis for each station.

Table 1: SPI Trend Analysis

Station	Z Values
Ladang Paya Lang, Segamat	-4.72
Pintu Kawalan Sembrong, Batu Pahat	-7.86
Kompleks Perumahan Pontian	-8.99
Stor JPS, Johor Bahru	6.57
Ladang Teluk Sengat, Kota Tinggi	7.20
Ladang Getah Malaya, Kota Tinggi	2.36
Ladang Pekan Layang - Layang, Kluang	-1.14
Bt 42 Jalan Kluang, Mersing	-6.49

From 8 selected rainfall stations, 5 of the stations showed a significantly decreasing trends. For the timescale computed, all 5 stations exhibited a statistically significant negative trend, indicating that conditions have gotten drier over the last 39 years. These stations include Ladang Paya Lang Segamat, Pintu Kawalan Sembrong Batu Pahat, Kompleks Perumahan Pontian, Ladang Pekan Layang-Layang Kluang and Bt 42 Jalan Kluang Mersing. By referring the linear trend line, Figure 3 shows the decreasing trend in SPI computed for 12-month scale

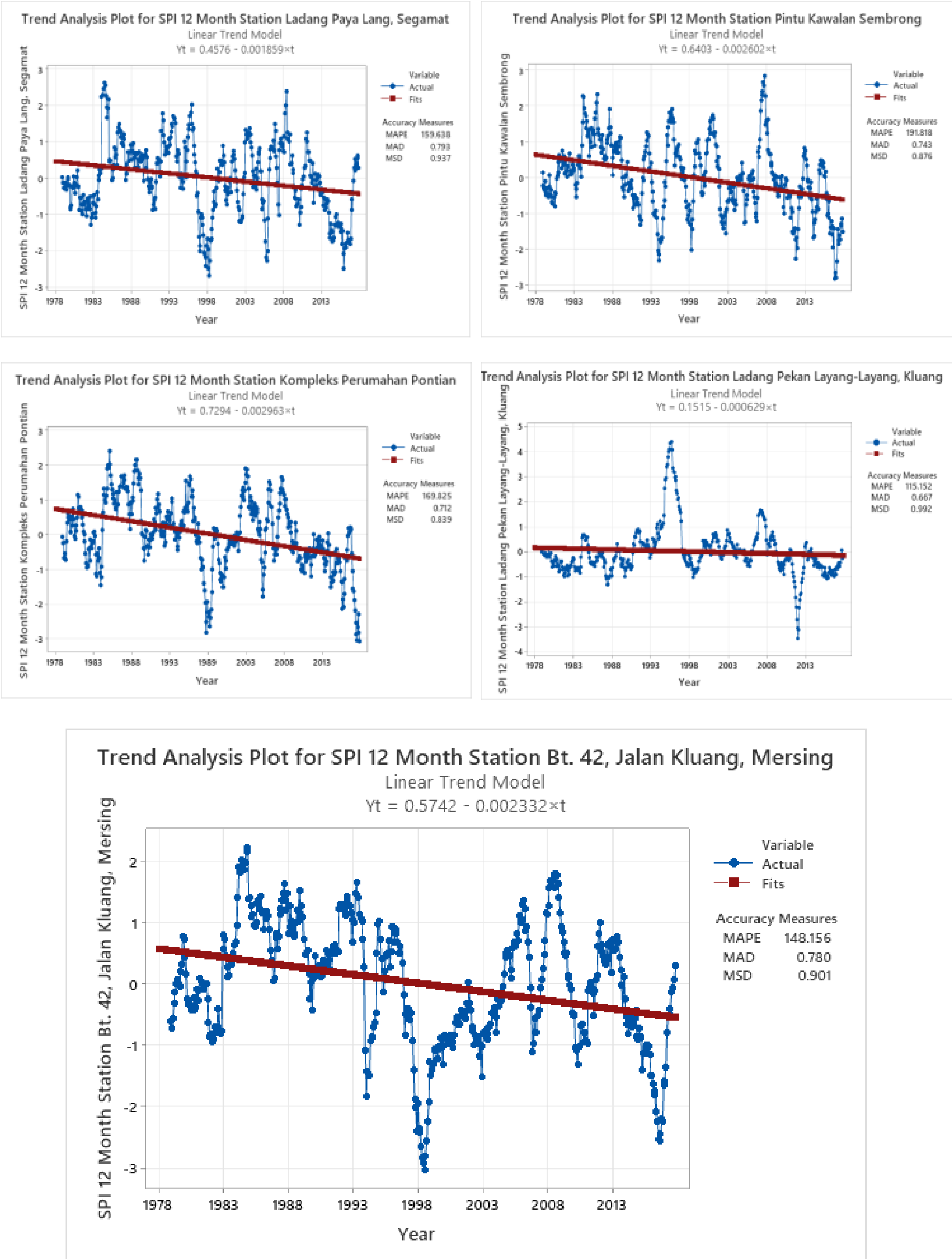

Figure 3: Stations with decreasing SPI trends

In contrast, 3 stations showed a notable increasing trend for all the SPI timescales used. These stations were Stor JPS Johor Bahru, Ladang Teluk Sengat Kota Tinggi and Ladang Getah Malaya Kota Tinggi. The increasing trends indicated that these areas were wetter compared to other selected rainfall stations. Figure 4 shows the increasing trend in the SPI computed in 12-month scale based on the linear trend line.

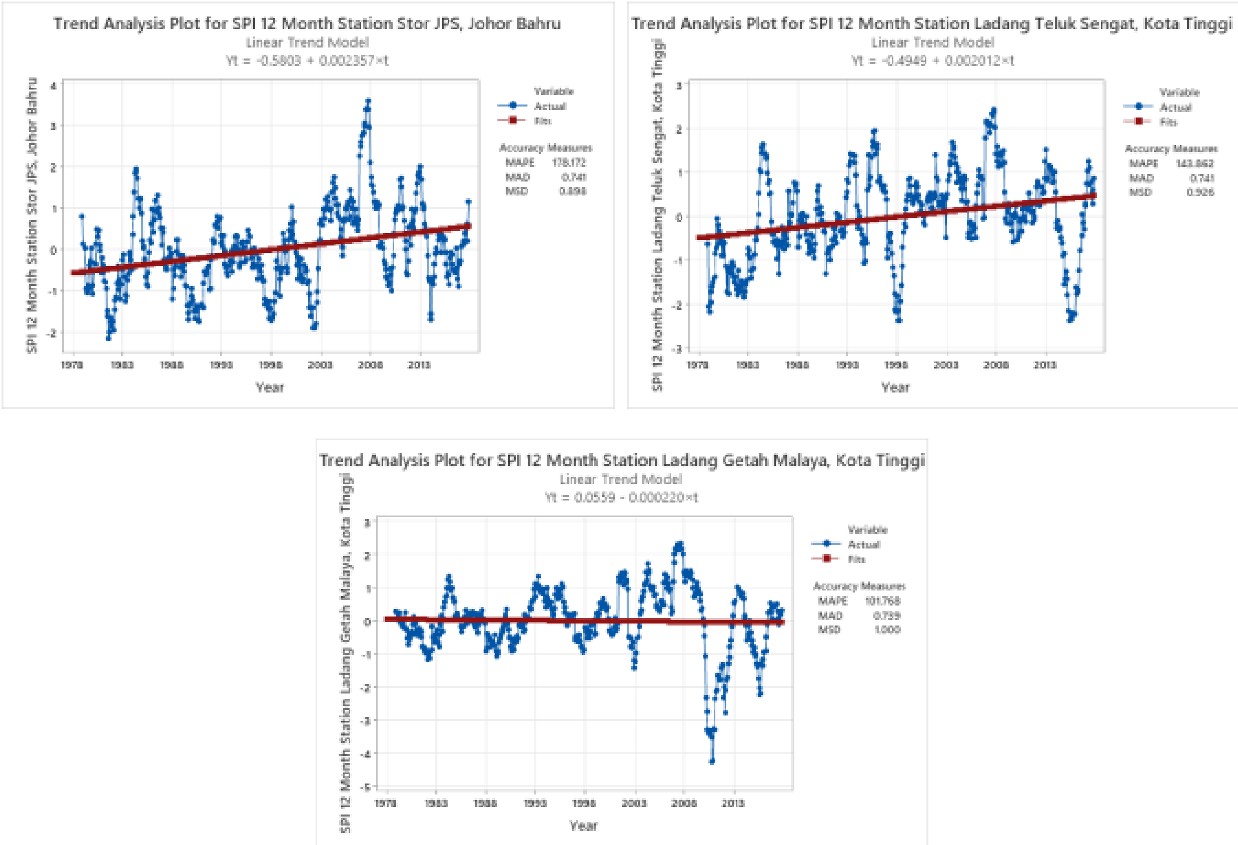

Figure 4: Stations with increasing SPI trends

4. Conclusion

In a nutshell, the objectives of this study were achieved. The missing data from the Department of Irrigation and Drainage were determined using the Arithmetic Mean method or Normal ratio method. From the SPI result, the wet and dry period were established and then compared with the historical extreme events recorded by previous studies. Next, the 12-month SPI timescale were shown to be the most appropriate combination of SPI and its timescale. This is because it reflects long term precipitation patterns. Lastly, based on the results obtained, the SPI values of the majority of the examined rainfall sites indicated a decreasing trend, while a few indicated an increasing trend. Therefore, the results of this study can be used for future planning and forecasting for Johor area as it contains the dry events and wet events for the past 39 years.

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