Spatiotemporal analysis of seasonal SPEI in Peninsular Malaysia

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Abstract. Precipitation prevails in Peninsular Malaysia throughout the year. However, the extremity and inconsistencies in the pattern and intensity of precipitation also subject Malaysia vulnerable to droughts and dry spells. There are two main factors affecting the climate pattern in Peninsular Malaysia, namely the Northeast Monsoon and the Southwest Monsoon. Therefore, it is important to monitor the climate pattern in these periods to offer better drought prediction in Peninsular Malaysia. The Standardized Precipitation Evapotranspiration Index (SPEI), an index that considers both precipitation and temperature variables was adopted in the study. Seasonal SPEIs were built for the periods of the Northeast Monsoon (SPEI-NEM), the first inter-monsoon (SPEI-Inter1), the Southwest Monsoon (SPEI-SWM) and the second inter-monsoon (SPEI-Inter2) to represent the drought severity during these four periods. 133 precipitation and 28 temperature stations with availability of data from year 1983 to 2017 (35 years) were used to construct the seasonal SPEIs for whole Peninsular Malaysia. The number of dry seasons identified by the indices were first been tested to investigate the linear trend of seasonal drought occurrence in each region. Then, severity represented by the indices were spatially interpolated over Peninsular Malaysia to produce an overview of the changes of moisture condition over distance. Trend analyses using the Mann-Kendall trend test and the Sen’s Slope were also carried out on the drought index series. The results showed that the occurrence of seasonal droughts had increase throughout the years investigated. The spatial interpolation of drought severities also showed dissimilar variation among the seasons but justifiable on the premise of climatic change caused by monsoon winds and the topography of the study area. Thereafter, the spatial analysis of seasonal drought trend has also been carried out where the SWM season was found to be the most drought vulnerable season in the future, with the Southern region being the most vulnerable as its trend tests showed increasing drought trend regardless of the season period. These suggest that the water resources planning in the future should focus more on the two mentioned aspects for sustainable water supply.

1. Introduction
Drought is a natural hazard formed from the deficit of precipitation for a period of time that subsequently, lead to a shortage in water supply. According to [1], risks management and mitigation for extreme climatic events such as drought are necessary to reduce the impact to the surrounding environment. For this purpose, researchers have poured in efforts to improve the reliability of monitoring and forecasting facilitation in managing drought [2],[3],[4],[5],[6],[7]. Compared to using direct climatic or hydrologic data as indicators, numerically expressed drought indices (DIs) show better effectiveness in detecting the onsets and offsets of droughts [8]. Over the years, various DIs such as the Percent of Normal, the Standardized Precipitation Index (SPI) [9], Palmer Drought
Severity Index (PDSI) [10], Crop Moisture Index (CMI) [11], Streamflow Drought Index (SDI) [12], Standardized Precipitation Evapotranspiration Index (SPEI) [13], etc. have been developed in the effort of assessing the water deficit associating to the duration of the precipitation shortage. Among them, the SPEI is the simplest scalable index that integrates the influence of both hydrological (precipitation) and ecological (potential evapotranspiration) variables in defining droughts operationally. Furthermore, it has been tested for its applicability in different parts of the world, which included the tropical, monsoon, Mediterranean, semi-arid, continental, cold, and oceanic climates [13]. Owing to these advantages, the SPEI has been widely applied to recent drought monitoring studies [14], [15], [16]. Therefore, considering the tropical climate in Peninsular Malaysia, the SPEI is selected as the drought index in this study.

Peninsular Malaysia is located in the humid tropical climate region and described by four seasons, which are the winter Northeast Monsoon season (NEM, from Nov to Feb), the summer Southwest Monsoon season (SWM, from May to Aug) and the two inter-monsoon seasons (Inter1, from Mar to Apr; and Inter2, from Sep to Oct) [17]. Most of the water supply in Peninsular Malaysia is sourced from surface waters, with only 3% sourced from groundwater. Thus, its freshwater supply can be affected easily and vulnerable to dry spells or droughts. Furthermore, it has been reported that there will be a future increment of the average annual air temperature of about 0.5°C-1.0°C during the period of 2030 (2020-2040), and further to 0.9°C -1.6 °C during the period of 2050 (2040-2060) [18]. Despite the drought risk that may increase due to the increment in air temperature, the monitoring of droughts in Peninsular Malaysia is based on SPI that solely considers precipitation [19]. Hence, the aim of this study is to analyze the spatiotemporal behavior of seasonal SPEIs over Peninsular Malaysia, which can consider the effects from both precipitation and temperature to provide valuable scientific reference for seasonal drought risk mitigation in Peninsular Malaysia as well as a preparation for better drought monitoring under the changing climate.

2. Materials and methods

2.1. Study area and data acquisition
The study area covers four regions in Peninsular Malaysia i.e. the Central Region, the East Coast Region, the Northern Region and the Southern Region. The Central Region consists of two main states, namely Kuala Lumpur and Selangor, with areas of 243 km² and 7,964 km² respectively. The East Coast regions is the largest region in Peninsular Malaysia, consisting Kelantan, Terengganu and Pahang states, covering a total area of 63,976 km². The Northern Region covers an area of 32,331 km² with the four states of Perlis, Kedah, Penang and Perak. As for the Southern Region, it consists of three states: Johor, Malacca, and Negeri Sembilan. These three states made up a total of 27,560 km² about 20.94% of lands for Peninsular Malaysia.

Climatic data used in this study was collected from the Department of Irrigation and Drainage, DID (precipitation) and the Malaysia Meteorological Department, MMD (temperature). Since defining a climate requires the minimum length of 30 years, stations with 35 years (1983 to 2017) of continuous monthly precipitation and mean temperature were selected for this study. There are 133 rainfall stations and 28 temperature stations, as shown in Figure 1. The homogeneity of the datasets was tested using the Standard Normal Homogeneity Test (SNHT) [20], the Pettit test [21], the Buishand Range Test [22] and the Von Neumann Ratio Test [23]; and these methods were found to be sufficient as reported in different studies involving meteorological time series [24], [25].
2.2. Standardized Potential Evapotranspiration Index (SPEI)

The SPEI is a multi-scalar drought index that considers both precipitation and evapotranspiration factors in describing drought using simple computation. It has a similar concept with SPI to describe droughts with different timescales, which allows monthly, seasonal and annual description of droughts. In addition, its consideration of evapotranspiration that solely based on temperature variation (not on soil moisture content as is the PDSI) also avoids it to be adversely affected by topography. SPEI values can be categorized according to classes (Table 1). Since the SPEI is a standardized index, it always has a mean value of zero, which represents normal moisture condition. Hence, the SPEI values are positive or negative to represent wet or dry conditions, respectively. The more negative SPEI value for a given location, the more severe the drought, or vice versa. In this study, the SPEI-NEM, SPEI-Inter1, SPEI-SWM and SPEI-Inter2 were constructed to represent the seasonal drought severity in Peninsular Malaysia, and the details on SPEI computation are given in the work of [13].

| Moisture Category  | SPEI          |
|--------------------|--------------|
| Extremely Wet      | 2.00 and above|
| Very Wet           | 1.50 to 1.99  |
| Moderately Wet     | 1.00 to 1.49  |
| Near Normal        | -0.99 to 0.99 |
| Moderately Dry     | -1.00 to -1.49|
| Severely Dry       | -1.50 to -1.99|
| Extremely Dry      | -2.00 and below|

2.3. Spatial Variation of Seasonal Droughts

In order to investigate the spatial variation of seasonal droughts across Peninsular Malaysia, the mean drought severity (MDS) for each station was estimated using the equations below:

\[
MDS = \frac{\sum_{j=1}^{N} DS_j}{N}
\]  

where DS is the drought severity quantified using the SPEI, N is the number of drought events observed during the study period, \( j \) represents drought event. Thereafter, the spatial interpolation of
these values using the Inverse Distance Weighting (IDW) method was carried out to analyse the spatial variations of drought characteristic across Peninsular Malaysia, as shown in the following equation:

\[ \hat{Z} = \frac{\sum_{i=1}^{n} \frac{Z_i}{d_i^k}}{\sum_{i=1}^{n} \frac{1}{d_i^k}} \]  

where \( \hat{Z} \) is the estimated value at an unsampled point, \( n \) is the number of control point used for estimation, \( k \) is the power of which distance is raised, \( d \) is the distances from each control points to unsampled point.

2.4. Mann-Kendall Trend Test and Sen’s slope

Trend tests were carried out in this study to test and quantify the trend in each index. In order to avoid the uncertainties in datasets and on whether it is normally distributed and independent, two non-parametric trend test techniques, i.e. the Mann-Kendall trend test to test the direction of trend [26] and the Sen’s slope to determine the magnitude of the resulting trend [27] are commonly used for trend analysis [28], [29], [30], [31]. The Mann-Kendall trend test is reproduced as below:

\[ S = \sum_{i=j}^{n} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \]  

where \( \text{sgn}(x_j - x_i) = \begin{cases} +1, x_j > x_i \\ 0, x_j = x_i \\ -1, x_j < x_i \end{cases} \)

\[ Z = \begin{cases} \frac{S-1}{\sqrt{\frac{n(n-1)(2n+5)}{6} \sum_{i=1}^{n-1} t_i(l(i-1)(2+5))}} & S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{\frac{n(n-1)(2n+5)}{6} \sum_{i=1}^{n-1} t_i(l(i-1)(2+5))}} & S < 0 \end{cases} \]  

where \( t_i \) is the ties of extent \( i \). The null hypothesis being tested is that no trend exists in the series. This is rejected if \(|Z| > 1.96 \) (95% confidence level) and significant trend exists. Positive values indicate increasing trend and vice-versa for negative values.

As for the Sen’s slope, it is used to define the magnitude of the trend using equation:

\[ Q_s = \frac{x_{j-i} - x_{j+i}}{j-i} \]  

where the median of the slope of \( Q_s \) series is arranged in increasing order to provide the Sen’s slope estimate.

3. Results and Discussion

3.1. Seasonal SPEI and Temporal Variation of Dry Seasons

The temporal evolution of the SPEI in different regions at various seasons may help us to understand the seasonal variation of droughts at a regional scale. The results of the SPEI-NEM, SPEI-Inter1, SPEI-SWM and the SPEI-Inter2 for each region are computed and shown in Figure 2.
Figure 2. Seasonal drought severity represented by SPEI at (a) the Central region, (b) the East Coast region, (c) the Northern region, and (d) the Southern region

Based on the results, it can be observed that severity ranges from the values of -2 to 2; suggesting that there is no significance difference in severity among the regions. In order to obtain better visualization, the number of dry seasons (max of four; only four seasons in Peninsular Malaysia) for each year was identified and tested for its linear trend. Although with different slope values shown, it was found the four regions are receiving an increasing number of dry seasons that is, an increasing trend. This suggests that Peninsular Malaysia has its occurrence of seasonal droughts increased throughout years from 1983 to 2017 and necessary actions ought to be taken in preparation to face the likely increasing occurrence of droughts in the future. Hence, further analyses on the spatial variation of drought severity in each season have been carried out, as illustrated in the next section.
3.2. Spatial Variation of Seasonal Droughts

Looking at Figure 3, it can be observed that the seasonal droughts that had occurred in Peninsular Malaysia have similar severity among the seasons, which are -0.641 ~ -1.05 in NEM season, -0.662 ~ -1.01 in Inter1 season, -0.612 ~ -1.12 in SWM season and -0.661 ~ -1.02 in Inter2 season. These severities show that the seasonal droughts occurred in Peninsular Malaysia fall in the category of either “Near Normal (0.00 ~ -0.99)” or “Moderately Dry (-1.00 ~ -1.49)” droughts. Although the droughts can be categorized in similar category, the drought severity still varies spatially and the variations differs among the seasons. For example, the seasonal droughts experienced at the stations located in the East Coast region and east coast area of the Southern region generally have lower severity in NEM due to the heavy rainfall brought by the north-easterly winds. In contrast, the influence from the SWM is smaller compared to the NEM due to the geographical location of Peninsular Malaysia being blocked by Sumatra Island. Hence, only few of the stations in the central area of the Northern region, central area of the Central region and northern area of the Southern region show relatively lower severity during the season.

As for the two inter-monsoon seasons (Inter1 and Inter2), the heat maps show relatively high severity at the inland areas. In other words, the stations at areas that are relatively further from coastlines were identified to have experienced droughts with higher severity compare to those located at the coastal areas. Without the assistance from monsoons to carry heavy rainfall, the rainfall events across Peninsular Malaysia during these two seasons are mainly convectional rainfalls. Hence, there is no significance difference in drought severity among the regions. However, with a higher evaporation and cloud development rate at the coastal areas, it is inevitable that the moisture conditions differ between the inland and coastal areas. Hence, it is reasonable that the heat maps for these two seasons (Figure 3(b) and Figure 3(d)) show higher drought severity at the inland areas of the Peninsular Malaysia.

![Figure 3. Heat maps of (a) SPEI-NEM, (b) SPEI-Inter1, (c) SPEI-SWM and (d) SPEI-Inter2 across Peninsular Malaysia](image)

3.3. Spatial Drought Trends

With the spatial variation of drought severity known, trend analysis has been carried out on each station and interpolated as maps (Figure 4) based on the magnitude detected by the Sen’s slope, the spatial variation in drought trend as preparation for future planning. Since the negative (positive) values of indices indicate dry (wet) condition, the red (blue) colour in the maps indicate increasing drying (wetting) trend. Figure 4 shows that the Southern region is the only region that has increasing drying trend for all the four seasons investigated; followed by the East Coast region and the Northern region where both were detected to have increasing drying trend for the Inter1, SWM and Inter2 seasons; and lastly, the Central region, which was detected to have increasing drying trend for the SWM season only. These results suggest that the SWM season will be the most drought vulnerable season for whole Peninsular Malaysia in the future. Apart from that, the Southern region was also...
found to have more droughts in the future regardless of the season period. Hence, water resources planning should start to focus more on these two aspects in order to ensure their sustainability.

Figure 4. Heat maps of drought severity trend across Peninsular for seasonal drought indices (a) SPEI-NEM, (b) SPEI-Inter1, (c) SPEI-SWM and (d) SPEI-Inter2

4. Conclusion
This paper presents the spatiotemporal variation of the seasonal droughts in Peninsular Malaysia. These droughts were represented using the SPEI-NEM for Northeast Monsoon season; the SPEI-SWM for Southwest Monsoon season; the SPEI-Inter1 and the SPEI-Inter2 for the two inter-monsoon seasons. The analyses on the temporal variation of the seasonal droughts were first carried out by testing on the linear trend in the number of dry seasons identified at the Central region, the East Coast region, the Northern region and the Southern region of Peninsular Malaysia. The results showed that all four regions exhibit increasing trend throughout years from 1983 to 2017. Thereafter, the spatial variations of the seasonal SPEIs were analyzed, with the results highlighting that the spatial variation of seasonal droughts in Peninsular Malaysia varies among the seasons. First of all, the spatial variation of droughts during the NEM season seemed to be affected by the heavy rainfall brought by the north-easterly winds and the hilly topography. Similarly, the droughts in the SWM season are also affected by the heavy rainfall brought by monsoon but from a different direction and smaller influence. As for the two inter-monsoon seasons, the spatial variations for both seasons were found to differ between inland and coastal areas. Finally, a spatial analysis on the drought trend was carried out as preparation for future planning. It was found that the SWM season seemed to be the most drought vulnerable season in the future, with the Southern region being the most vulnerable as its trend tests showed increasing drought trend regardless of the season period. Future water resources planning should start with focusing more on these two aspects in order to ensure sustainable water supply for Peninsular Malaysia.

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