Evaluation of Drought Conditions in Peninsular Malaysia during 1989-2018 using SPI and EDDI

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ABSTRACT

Droughts are constantly threatening the global water availability and food securities worldwide. This study aims to evaluate the short- and long-term (1-, 6- and 12-month) drought conditions in Peninsular Malaysia during 1989-2018 using Standardized Precipitation Index and Evaporative Demand Drought Index. Historical trends of drought conditions were analyzed using modified Mann-Kendall test. Spearman's ϱ approach was also applied to examine the spatial patterns of correlations between these drought indices. Based on the findings, Evaporative Demand Drought Index shows increasing tendency towards drier conditions in the northern half of Peninsular Malaysia, but opposite trends are observed for Standardized Precipitation Index. The time series of Evaporative Demand Drought Index are generally well-correlated to that of Standardized Precipitation Index at all three timescales for the whole study area, except for the northern region. The evidence presented suggests Evaporative Demand Drought Index is a great alternative for drought monitoring applications in Peninsular Malaysia.

Keywords: Evaporative Demand Drought Index, Drought Trend Analysis, Peninsular Malaysia

1 Introduction

Drought is a recurring extreme precipitation event over land that arises from considerable deficiency in rainfall [1]. It is defined as a dry spell relative to its local normal condition, thus it can occur even in wet and humid regions. It is one of the most complex natural phenomena due to the difficulty in identifying and predicting its onset and end [2]. According to the World Health Organization, an estimated 55 million people globally are affected by droughts every year, with 700 million people at risk of being displaced by 2030 due to the impacts of water scarcity [3]. As global warming continues, its adverse effects on food supply and water security will be further amplified in the context of climate change.

The existing natural disaster mitigation measure in Peninsular Malaysia is more focused on flood emergency scenario rather than drought recovery due to the abundant amount of annual rainfall. Hence, it can be detrimental when severe drought events occur. In fact, the prolonged period of dry spells during 1997/1998 and 2015/2016 that caused water shortage in major cities such as Kuala Lumpur and Johor are strong signals of our vulnerability towards extreme drought conditions under the climate change impacts [4]. To further understand the spatiotemporal characteristics of drought in Peninsular Malaysia, Fung *et al.* [4] have conducted a drought analysis using Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI). They found increasing drought conditions for the southern region of Peninsular Malaysia. In contrast, He *et al.* [5] found tendency towards wetter conditions over most regions of Peninsular Malaysia, except the northern region. The findings by Fung *et al.* [4] are generally in agreement

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with Gevaert *et al.* [6] that drought indicators tend to be more responsive towards short-term drought in this region, especially at 1-month timescale. The frequent short-term drought could be due to the alternating high temperature and extreme rainfall in Peninsular Malaysia [4]. Nevertheless, all these previous studies in Peninsular Malaysia only utilized limited numbers of drought indicators, namely SPI, SPEI and Palmer Drought Severity Index (PDSI), which have limitations in capturing the rapidly evolving drought at sub-monthly timescale (flash drought) [7]. The rapid onset of flash drought significantly reduces the time available for disaster preparation measures, thus has more severe impact on socioeconomic activities than a slower developing but persisting drought [8]. Recently, an evaporation-based multiscalar drought index known as Evaporative Demand Drought Index (EDDI) has been introduced by Hobbins *et al.* [9] to address this issue. This drought index has the advantage of being sensitive to rapid changes in soil moisture and can provide early warnings on flash drought development at weekly timescale, which is useful for drought monitoring application in region experiencing frequent flash drought such as Peninsular Malaysia.

This study aims to examine the application of EDDI in drought analysis for Peninsular Malaysia in comparison to SPI. These two drought indices were computed at three different timescales (1-, 6- and 12-month) over 1989–2018 by using the climate data from European Centre for Medium-range Weather Forecasts ReAnalysis 5 (ERA5) dataset [10].

2 Study Area and Data

Peninsular Malaysia, also known as West Malaysia, is chosen as the study area (Figure 1). Peninsular Malaysia can be divided into five main climatic regions based on the rainfall clustering analysis conducted by Bakar *et al.* [11] and Lim [12]. Peninsular Malaysia receives around 2500 mm rainfall annually [13], with its climate greatly modulated by the tropical monsoon system. The rainfall seasons in Peninsular Malaysia can be categorized into four, which are northeast and southwest monsoon seasons, with two inter-monsoon seasons in between [14].

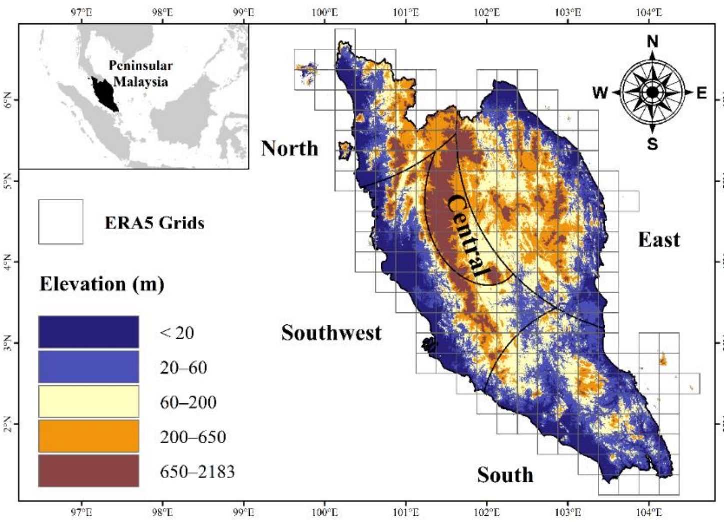

Figure 1: *Topographical map for Peninsular Malaysia. The thick black lines represent the boundaries of climatic regions, while the grey boxes represent areas covered by the grids of ERA5 dataset.*

To compute SPI and EDDI, five atmospheric variables are required; they are rainfall, temperature, dewpoint temperature, solar radiation, and wind speed. These climatic data was obtained from the 0.25°×0.25° ERA5 hourly reanalysis dataset by the European Centre for Medium-Range Weather Forecasts (ECMWF) [10] due to limitation in availability of observation data for Peninsular Malaysia. A total of 239

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grids from the reanalysis dataset were selected based on its spatial resolution to completely cover the study area (Figure 1). The total duration for this study is 30-year period (from 1989 to 2018).

3 Methods

3.1 Drought Index Formulation

In this study, two drought indices, namely SPI and EDDI, were chosen for the assessment. These drought indices were computed at three temporal scales which are 1-, 6- and 12-month timescales. SPI is a precipitation-based index measuring the probability of rainfall occurrence within a certain period [2]. It was chosen as the benchmark for the comparison as it is among the most recognized indicator in drought analysis [15, 16]. SPI was computed for all individual grid following the methodology by McKee *et al.* [2]. Positive SPI values indicate surplus of rainfall while negative SPI values indicate deficit of rainfall.

EDDI is computed based on the evaporative demand (E_0) of the atmosphere [9]. To calculate E_0, the American Society of Civil Engineers (ASCE) standardized reference evapotranspiration equation [17] was applied. The estimation of E_0 is derived from the Penman–Monteith equation [18]. To compute this ASCE version of the Penman–Monteith equation, it requires surface downwards solar radiation, mean air temperature, dewpoint temperature and wind speed data, which were extracted from ERA5 datasets. A negative EDDI values indicate wet conditions and positive values indicate dry conditions, with drought severity increasing with greater positive EDDI value.

3.2 Trend Analysis and Correlation Test

For trend detection, the Mann-Kendall test was adopted to identify the tendency of the drought indices. It is a nonparametric rank-based statistical test which is more robust towards outliers regardless of the distribution of time series. The null hypothesis of the Mann-Kendall test indicates stationary trend over the time series, whereas the alternative hypothesis indicates the presence of monotonic upward or downward trend. This study adopted the modified version of Mann-Kendall test (MMK) to consider significant autocorrelations exist in the time series [19]. The difference between original Mann-Kendall test and MMK test is the original variance, $Var_0(S)$ was recalculated as $Var_1(S)$ in MMK test when the coefficient of the ranks of the data exceeds of the 95% interval as shown in Equation 1:

$$Var_1(S) = Var_0(S) \times \frac{n}{n_e} \quad (1)$$

where n is the actual sample size and n_e is the effective sample size for the data. The n/n_e ratio is the correction factor to $Var_0(S)$ to consider the autocorrelations in the time series. Positive (negative) MMK value indicates upward (downward) trend.

The correlation between EDDI and SPI was calculated by applying the nonparametric Spearman's ϱ correlation test at 0.01 significance level [20]. It measures the relationship between the rank values of two variables, with the value +1 (-1) indicates a perfect positive (negative) association, while zero value indicates no correlation between these two variables.

4 Results and Discussions

4.1 Spatial Distributions of Trends

The spatial distributions of trends for EDDI shows that there are significant increases in drought conditions at regions between 4°N and 6°N for 1-, 6- and 12-month timescales (Figure 2). In contrast, SPI shows significant decreases in drought conditions in most part of Peninsular Malaysia as the timescale increases.

The difference in trends between SPI and EDDI can be explained by the climatic variables used to compute each drought index. The SPI only considers precipitation deficit, whereas EDDI takes into account the drying conditions in the atmosphere [21]. Previous study found precipitation extremes are increasing significantly in the east coast, northern and southwest regions [13]. The increasing rainfall at the similar regions could be the main factors for reductions in drought conditions indicated by SPI due to its dependency on rainfall data in its formulation. In contrast, the evapotranspiration based EDDI are more sensitive to drought that are driven by changes in the other atmospheric drivers such as temperature, solar radiation, wind speed and relative humidity [22]. In previous research by Fung *et al.* [4] in Peninsular Malaysia, they have reported increasing trends for monthly temperature in all regions. This could have resulted in the increasing trends for EDDI. Nonetheless, the other climatic forcings such as wind speed and relative humidity also play important roles in driving the drought conditions indicated by EDDI [9]. Therefore, the trends of other climatic variables need to be further analyzed to identify the factors for deviation of results.

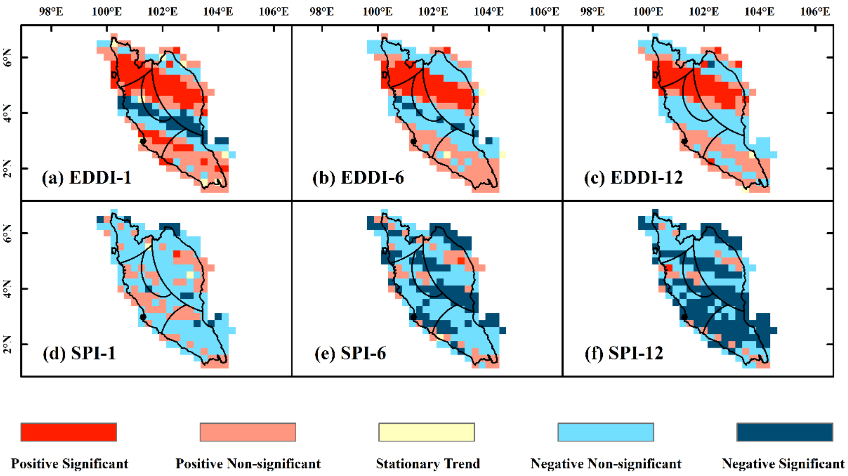

Figure 2: *Spatial patterns of trends for drought indices over Peninsular Malaysia during 1989–2018.*

4.2 Time Series and Correlations

The regional averaged time series of SPI and EDDI at 1-, 6- and 12-month timescales were computed for the whole Peninsular Malaysia over 1989–2018. Figure 3 shows that time series for EDDI is strongly identical to that of SPI at all timescales. Note that the y-axes of EDDI are inverted to facilitate the comparison of drought severity relative to SPI. The graph demonstrates that the peak and dip of time series are well-captured by EDDI at all timescales throughout the study period. This shows that EDDI is robust in measuring droughts at both long-term and short-term durations. The time series of these two indices are strongly correlated (< -0.8) at 99% level for all timescales (Figure 3). Their correlation is the highest at 6-month timescale, followed by 12-month and 1-month. The strong correlations between EDDI and SPI are in agreement with the findings by Yao *et al.* [21] for mainland China. From Figure 4, the regions with lower correlations between EDDI and SPI are mainly located between 100°E and 102°E longitude and 4.5°N and 5.5°N latitude. These are the regions with higher annual temperature [23] but still receive huge amount of rainfall annually [13]. Under this atmospheric condition, SPI tends to indicate wet conditions, but EDDI tends to produce opposite results due to their dependencies on different variables. Therefore, lower correlations between EDDI and SPI in these regions are expected. The correlations for all grids are statistically significant at 0.01 significance level, except three grids located at the northern region at 12-month timescale.

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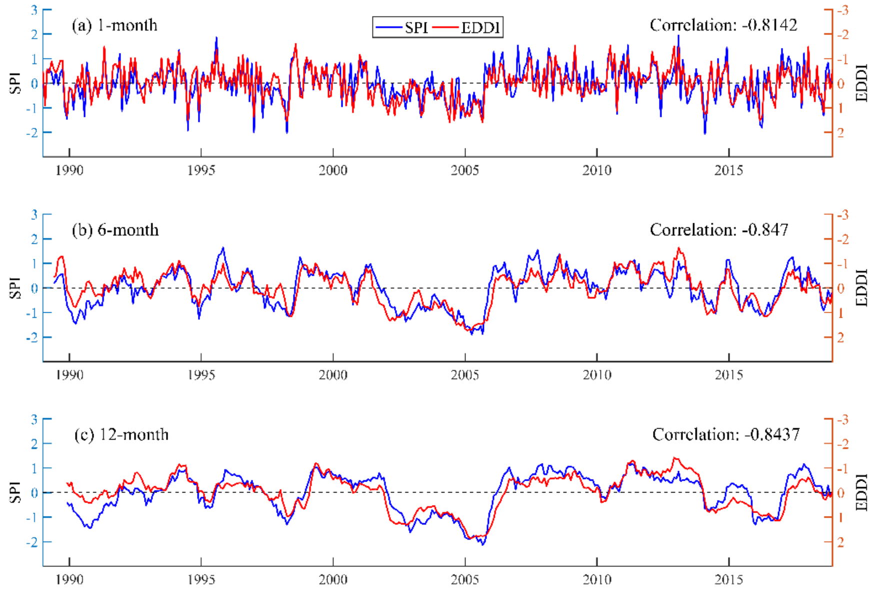

Figure 3: *Regional averaged time series of EDDI (red line) and SPI (blue line) at (a) 1-month, (b) 6-month and (c) 12-month timescales for Peninsular Malaysia over 1989–2018.*

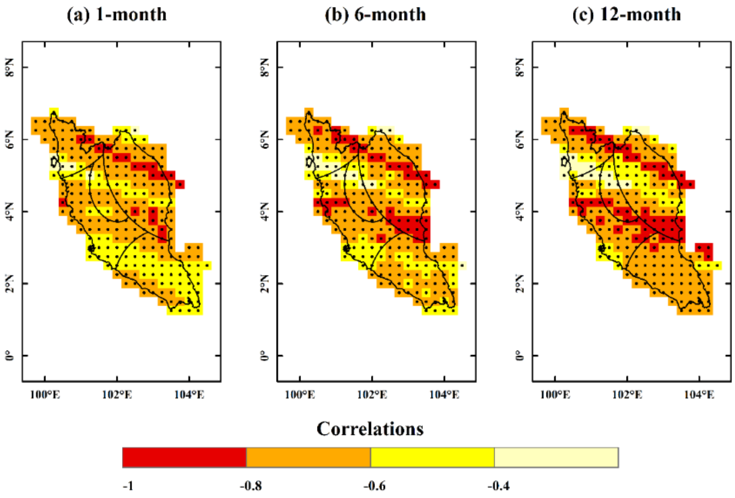

Figure 4: *Spatial distributions of correlations between EDDI and SPI at (a) 1-month, (b) 6-month and (c) 12-month timescales for Peninsular Malaysia over 1989–2018. The black dots indicate statistically significant at 0.01 significance level.*

5 Conclusions

This study focused on the evaluation of drought conditions in Peninsular Malaysia during 1989–2018 using SPI and EDDI as the drought indicators. Trend analysis found mixed signals from these drought indices for the northern half of Peninsular Malaysia, which are likely due to their dependencies on different climatic variables in their formulations. For all timescales, EDDI performed consistently well in matching the drought severities indicated by SPI throughout the study period. The spatial distributions of correlations also demonstrate that EDDI is well-correlated with SPI over the study area. The findings of this study show that EDDI can be a great alternative to SPI in drought monitoring applications, but the characteristics of E_0 and the performance of EDDI during severe droughts need to be further studied to ensure its applicability in Peninsular Malaysia. This study also verifies that Peninsular Malaysia is susceptible to drought risks, despite high annual rainfall.

6 Declarations

6.1 Acknowledgements

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6.3 Competing Interests

All authors declare that they have no conflicts of interest.

6.4 Publisher's Note

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References

[1] Z. Amin, S. Rehan, N. Bahman, and I. K. Faisal, "A review of drought indices," *Environmental Reviews*, vol. 19, pp. 333-349, Sept. 2011. https://doi.org/10.1139/A11-013

[2] T. B. McKee, N. J. Doesken, and J. R. Kleist, "The relationship of drought frequency and duration to time scales," in *8th Conf. on Applied Climatology*, Anaheim, CA, Jan. 1993. Access online on 23 May 2022 at https://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf

[3] United Nations Convention to Combat Desertification, "Drought in numbers 2022: Restoration for readiness and resilience," May. 2022. Access online on 28 May 2022 at https://www.unccd.int/resources/publications/drought-numbers

[4] K. F. Fung, Y. F. Huang, and C. H. Koo, "Assessing drought conditions through temporal pattern, spatial characteristic and operational accuracy indicated by SPI and SPEI: Case analysis for Peninsular Malaysia," *Natural Hazards*, vol. 103, no. 2, pp. 2071-2101, Sept. 2020. https://doi.org/10.1007/s11069-020-04072-y

[5] Q. He *et al.*, "Tropical drought patterns and their linkages to large-scale climate variability over Peninsular Malaysia," *Hydrological Processes*, vol. 35, no. 9, pp. e14356, Aug. 2021. https://doi.org/10.1002/hyp.14356

[6] A. I. Gevaert, T. I. E. Veldkamp, and P. J. Ward, "The effect of climate type on timescales of drought propagation in an ensemble of global hydrological models," *Hydrology and Earth System Sciences*, vol. 22, no. 9, pp. 4649-4665, Sept. 2018. https://doi.org/10.5194/hess-22-4649-2018

[7] Z. Hao, F. Hao, V. P. Singh, and X. Zhang, "Statistical prediction of the severity of compound dry-hot events based on El Niño-Southern Oscillation," *Journal of Hydrology*, vol. 572, pp. 243-250, May. 2019. https://doi.org/10.1016/j.jhydrol.2019.03.001

[8] J. A. Otkin *et al.*, "Facilitating the use of drought early warning information through interactions with agricultural stakeholders," *Bulletin of the American Meteorological Society*, vol. 96, no. 7, pp. 1073-1078, Jul. 2015. https://doi.org/10.1175/bams-d-14-00219.1

[9] M. T. Hobbins *et al.*, "The Evaporative Demand Drought Index. Part I: Linking drought evolution to variations in evaporative demand," *Journal of Hydrometeorology*, vol. 17, no. 6, pp. 1745-1761, Jun. 2016. https://doi.org/10.1175/jhm-d-15-0121.1

[10] H. Hersbach *et al.*, "Operational global reanalysis: Progress, future directions and synergies with NWP," Dec. 2018. Access online on 28 May 2022 at https://www.ecmwf.int/node/18765

[11] M. A. A. Bakar, N. M. Ariff, A. A. Jemain, and M. S. M. Nadzir, "Cluster analysis of hourly rainfalls using storm indices in Peninsular Malaysia," *Journal of Hydrologic Engineering*, vol. 25, no. 7, pp. 05020011, Apr. 2020. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001942

[12] J. T. Lim, "Rainfall minimum in Peninsular Malaysia during the northeast monsoon," *Monthly Weather Review*, vol. 104, no. 1, pp. 96-99, Jan. 1976. https://doi.org/10.1175/1520-0493(1976)104<0096:Rmipmd>2.0.Co;2

[13] C. Y. Ng, W. Z. Wan Jaafar, Y. Mei, F. Othman, S. H. Lai, and J. Liew, "Assessing the changes of precipitation extremes in Peninsular Malaysia," *International Journal of Climatology*, May. 2022. https://doi.org/10.1002/joc.7684

[14] W. Z. W. Zin, S. Jamaludin, S. M. Deni, and A. A. Jemain, "Recent changes in extreme rainfall events in Peninsular Malaysia: 1971-2005," *Theoretical and Applied Climatology*, vol. 99, no. 3-4, pp. 303-314, Jan. 2010. https://doi.org/10.1007/s00704-009-0141-x

[15] Y. Li *et al.*, "Meteorological and hydrological droughts in Mekong River Basin and surrounding areas under climate change," *Journal of Hydrology: Regional Studies*, vol. 36, pp. 100873, Aug. 2021. https://doi.org/10.1016/j.ejrh.2021.100873

[16] C. Liu, C. Yang, Q. Yang, and J. Wang, "Spatiotemporal drought analysis by the standardized precipitation index (SPI) and standardized precipitation evapotranspiration index (SPEI) in Sichuan Province, China," *Scientific Reports,* vol. 11, no. 1, pp. 1280, Jan. 2021. https://doi.org/10.1038/s41598-020-80527-3

[17] R. P. Allan, B. J. Soden, V. O. John, W. Ingram, and P. Good, "Current changes in tropical precipitation," *Environmental Research Letters,* vol. 5, no. 2, pp. 025205, Apr. 2010. https://doi.org/10.1088/1748-9326/5/2/025205

[18] J. L. Monteith, "Evaporation and environment," *Symposia of the Society for Experimental Biology,* vol. 19, pp. 205-234, Jan. 1965. Access online on 28 May 2022 at https://repository.rothamsted.ac.uk/item/8v5v7/evaporation-and-environment

[19] K. H. Hamed and A. Ramachandra Rao, "A modified Mann-Kendall trend test for autocorrelated data," *Journal of Hydrology,* vol. 204, no. 1, pp. 182-196, Jan. 1998. https://doi.org/10.1016/S0022-1694(97)00125-X

[20] C. Spearman, "The proof and measurement of association between two things," *The American Journal of Psychology,* vol. 15, no. 1, pp. 72-101, Jan. 1904. https://doi.org/10.2307/1412159

[21] N. Yao, Y. Li, T. Lei, and L. Peng, "Drought evolution, severity and trends in mainland China over 1961–2013," *Science of The Total Environment,* vol. 616-617, pp. 73-89, Mar. 2018. https://doi.org/10.1016/j.scitotenv.2017.10.327

[22] D. J. McEvoy *et al.*, "The Evaporative Demand Drought Index. Part II: CONUS-Wide Assessment against Common Drought Indicators," *Journal of Hydrometeorology,* vol. 17, no. 6, pp. 1763-1779, Jun. 2016. https://doi.org/10.1175/jhm-d-15-0122.1

[23] M. L. Tan, L. Juneng, F. T. Tangang, J. X. Chung, and R. B. Radin Firdaus, "Changes in temperature extremes and their relationship with ENSO in Malaysia from 1985 to 2018," *International Journal of Climatology,* vol. 41, no. S1, pp. E2564-E2580, Oct. 2020. https://doi.org/10.1002/joc.6864