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ADVANCING ENVIRONMENTALLY SUSTAINABLE GROWTH: A STATISTICAL NARRATIVE

Statistical Comparison of SPEI – 1 Month and SPEI – 3 Month: Enhancing Consistency in Drought Assessment

Halimatun Sa'adiah Md Salehan[1], Noor Elidawati Bahari[2], and Adlyn Syahirah Zulcafli[3]

[1 2 3] University College Agroscience Malaysia, 78000, Alor Gajah, Melaka, Malaysia

Abstract:
Drought assessment is essential in water management, environmental conservation, and agriculture planning. The Standardized Precipitation Evapotranspiration Index (SPEI) gained widespread usage for drought assessment. This index used precipitation data (rainfall) and evapotranspiration data (temperature). The choice between using a short-time scale SPEI – 1 month and a long-timescale SPEI 3 – months for drought analysis can lead to inconsistency in the analysis result of drought assessment. This paper aims to conduct a statistical comparison between SPEI – 1 month and SPEI – 3 months' timescale in enhancing the consistency in drought assessment. This comparison aims to identify the strengths and weaknesses of each timescale while providing new insight into the appropriate timescale usage.

Keywords:
Drought assessment; Standardized Precipitation Evapotranspiration Index (SPEI); Timescale; Consistency

1. Introduction:
Droughts have severe implications on socioeconomic systems and natural ecosystems [1]. Accurate assessment methods, such as the Standardized Precipitation Evapotranspiration Index (SPEI), are crucial for mitigating their impact [2]. SPEI offers multiple timescales, such as SPEI-1 month and SPEI-3 months, which can lead to inconsistencies in drought assessments [4, 7]. Despite the importance of timescale selection, comprehensive statistical comparisons are lacking [8]. This study aims to fill this gap by statistically comparing SPEI-1 months and SPEI-3 months to enhance the consistency and accuracy of drought assessments.

Drought assessment plays a critical role in sectors like agriculture, water management, and disaster preparedness. It also has health implications [9]. The Standardized Precipitation Index (SPI) has been traditionally used for drought monitoring, relying solely on precipitation data [9, 10]. However, the introduction of temperature data in SPEI has made it a more comprehensive index [6]. Previous studies have found that the choice of timescale significantly influences drought assessment [10, 14]. This study extends this line of inquiry by statistically comparing the SPEI-1 month and SPEI-3 months timescales to identify their respective strengths and limitations for drought assessment.

2. Methodology:

The study utilized climatological data from the Malaysian Meteorological Department, focusing on the state of Malacca from 1993 to 2022. The data was sourced from weather stations with consistent, high-quality records [16]. Any missing or incomplete data was filled using interpolation methods [17]. Stations with more than 10% missing data were excluded to maintain data quality. Prior to analysis, the data underwent rigorous cleaning and validation [18]. This approach ensures the reliability and validity of the SPEI time scale analyses [15].

The Standardized Precipitation Evapotranspiration Index (SPEI) enhances the Standardized Precipitation Index (SPI) by incorporating potential evapotranspiration (PET), offering a more comprehensive water balance approach [19]. SPEI calculations require standardized monthly precipitation and PET data [2]. The PET value (PETt) is computed using the Thornwaite equation.

$$PETt = 0.6\left[10\left(\frac{T}{T+10}\right)\right]^{a}\left(\frac{12}{12}\right) \quad (1)$$

where T represents the monthly mean temperature in Celsius, and the value of a varies based on latitude. The value of a can be determined using empirical relationships.

A standard climate period generally spans 30 years and represents average climatic conditions [20]. Monthly long-term averages for precipitation (Pn) and PET (PETn) are used as reference standards. These are standardized using specific equations.

$$SP = P - Pn \quad (2)$$

$$PET = PETt - PETn \quad (3)$$

To calculate standardized accumulated precipitation (ASP) and PET (ASPET) for time scales like 1 and 3 months, adjusted values for the current and previous months are summed. For instance, the equation for 3-month ASP is used.

$$ASP = SPt + SP(t-1) + SP(t-2) \quad (4)$$

$$ASPET = PETt + PET(t-1) + PET(t-2) \quad (5)$$

where t represents the current month. Finally, the SPEI is calculated as the ratio of the standardized accumulated precipitation to the standardized PET as follows:

$$SPEI = \frac{ASP}{ASPET} \quad (6)$$

In this study, we use R and the SPEI package to calculate SPEI at 1-month and 3-month timescales based on the Thornwaite equation. The software estimates reference evapotranspiration (ETo) from temperature data and combines it with precipitation to generate SPEI values.

Drought conditions are categorized based on SPEI values, in line with guidelines from [20] and [2]. The criteria are consistent for 1-month and 3-month timescales. The classification scheme is:

TABLE 1. Classification of SPEI

Index	Classification
> 2.0	Extremely wet
1.5 – 2.0	Very wet
1.0 – 1.5	Moderately wet
-1.0 – 1.0	Near Normal
-1.5– -1	Moderately dry
-2.0 - -1.5	Severely dry
< -2.0	Extremely dry

Before primary analyses, we'll check the normality of SPEI-1 and SPEI-3 datasets using histograms, Q-Q plots, and Shapiro-Wilk or Kolmogorov-Smirnov tests [21][22]. Post-verification, we'll visualize both datasets as time series plots [23], examining trends and seasonality [24]. Autocorrelation plots will also be used to study temporal relationships [25].

Descriptive statistics like mean, median, and standard deviation will be calculated for both datasets [26]. If the datasets are normally distributed, an independent sample t-test will be used to compare SPEI-1 and SPEI-3 [27]. Otherwise, a Mann-Whitney U test will be applied.

We'll employ the Spearman correlation coefficient to assess the correlation between SPEI-1 and SPEI-3 [28]. Lastly, a sensitivity analysis will be conducted to test the robustness of our findings [29]. All analyses are exploratory and should consider data limitations.

The Bland-Altman method is used to assess the agreement between SPEI-1 and SPEI-3 time scales. This involves plotting the mean and differences of each data point from both methods on a scatter plot, allowing for visual inspection of biases and outliers [30]. The average of differences (bias) and limits of agreement are calculated [31]. The plot includes lines for mean difference and limits, aiding interpretation. Normality of differences should be verified, possibly using the Shapiro-Wilk test [21]. The method offers both visual and quantitative insight into the consistency between SPEI-1 and SPEI-3.

The evaluation phase will assess the strengths and weaknesses of SPEI-1 and SPEI-3, using results from the Bland-Altman method and their practical utility in drought assessment. We'll first examine each timescale's sensitivity to climatic changes for early warning or long-term trend detection. Next, we'll evaluate their performance in identifying various types of historical drought events, including their start, end, and duration.

The goal is to understand each timescale's applicability and limitations for drought monitoring. While the findings may not be universally applicable, they provide insights into the timescales' performance under specific conditions.

3. Result:

Our study conducts a thorough statistical analysis of SPEI-1 and SPEI-3 datasets, classifying drought conditions based on guidelines from Vicente-Serrano et al. [2] and Beguería et al. [7]. For instance, the SPEI-1 value for January 1993 is -0.037333, falling under the "Near Normal" category. Normality was assessed using histograms, Q-Q plots, and the Shapiro-Wilk test [21]. While SPEI-1 was normally distributed, SPEI-3 showed slight deviations from normality.

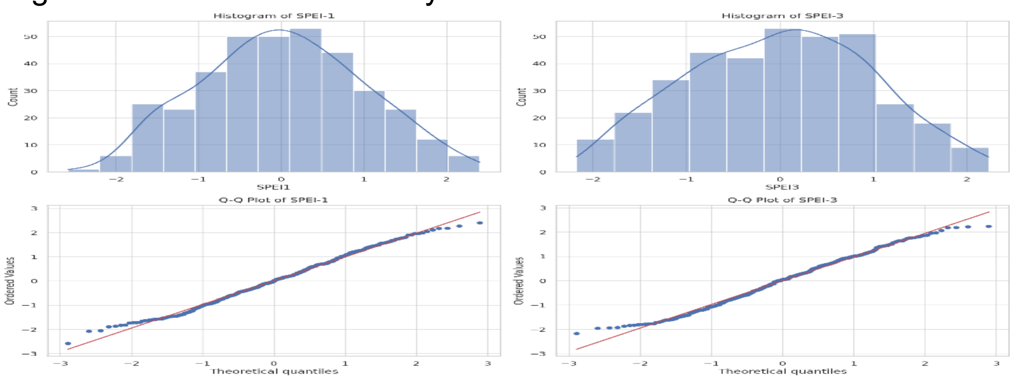

FIGURE 1. Histogram and Q – Q plots

We used the Shapiro-Wilk test to assess normality. For SPEI-1, the test yielded a p-value of 0.063, indicating normal distribution [21]. For SPEI-3, the p-value was 0.007, suggesting non-normal distribution, requiring non-parametric tests. Time series and autocorrelation plots showed some degree of autocorrelation in both datasets [23, 25]. Descriptive statistics revealed both sets are approximately symmetrical with lighter tails [26].

FIGURE 2. Time series plot

Following a detailed analysis, we have computed descriptive statistics for the SPEI-1 and SPEI-3 datasets. Here is the table presenting the descriptive statistics for the SPEI-1 and SPEI-3 datasets:

TABLE 2. Descriptive Result

Statistic	SPEI-1	SPEI-3
Mean	0.01012	-0.0002
Standard Deviation	0.97709	0.97392
Skewness	0.05737	0.0121
Kurtosis	-0.5511	-0.6702

Key statistical values for SPEI-1 and SPEI-3 are summarized in a table, providing an overview of each dataset's distribution. We used the Mann-Whitney U test due to SPEI-3's non-normal distribution, finding no significant difference between the datasets' central tendencies [27]. Spearman correlation showed a moderate positive correlation (0.588) between them [28]. Sensitivity analysis and Bland-Altman method confirmed reasonable agreement between the datasets, with a bias of 0.0103 and limits of agreement between -1.68 and 1.70 [30, 31].

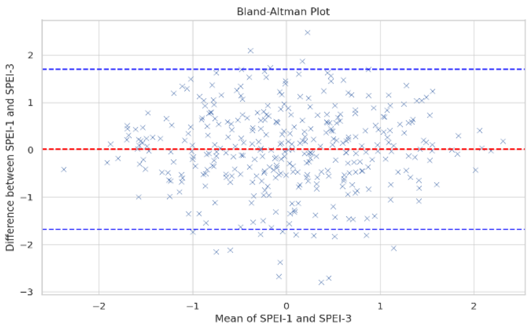

FIGURE 3. Bland – Altman Plot

4. Discussion and Conclusion:

Our study offers an in-depth analysis of SPEI-1 and SPEI-3 datasets for assessing drought conditions [2]. Both indices have unique strengths: SPEI-1 excels in real-time monitoring, beneficial for agriculture [1], while SPEI-3 is suited for long-term risk assessment and policy planning [2]. Despite their differing temporal scales, they showed a high degree of consistency [27], supported by a moderate positive correlation [28].

The choice between the two should be context-dependent, aligned with specific objectives rather than purely statistical considerations. Sensitivity analysis showed SPEI-1 as an early warning system and SPEI-3 as reliable for long-term trends. Both are valuable across sectors, including water management and disaster risk reduction [37].

However, the study has limitations such as focus only on two temporal scales and being potentially region-specific. Future research should explore other SPEI scales and sectors, and validate the findings across different climates.

In summary, SPEI-1 and SPEI-3 are robust tools for drought assessment, but their optimal use varies by objective and sector. Continued research will refine drought management strategies.

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