



Comparative study of SPI and SPEI drought indices for meteorological drought assessment in Mauritius

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Drought is a global issue affecting many countries, including Mauritius, which is vulnerable to this natural hazard. This study compares two robust drought indices: the Standardised Precipitation Index (SPI) and its variant the Standardised Precipitation Evapotranspiration Index (SPEI) using statistical techniques, to determine the most appropriate drought assessment tool for Mauritius, as a Small Island Developing State (SIDS). The study utilised monthly averaged rainfall, maximum and minimum temperature data from six meteorological stations spanning 1971–2017. Standardised Precipitation Index and SPEI values were computed at 1, 3, 6 and 12-month timescales using the SPEI package in *R-Programming*. Three statistical tests: Pearson's Correlation, Cohen Kappa's Statistics and Bland-Altman were applied to assess the relationship between these indices. Strong correlations were observed with Pearson's correlation showing ($r > 0.9, p < 0.01$), Cohen's Kappa test revealed 'almost perfect agreement' with values reaching +0.95 at 3-month timescale and +0.94 for the remaining timescales, finally Bland-Altman plots further confirmed acceptable agreement. This study concluded that both SPI and SPEI could effectively assess drought in Mauritius.

Contribution: Mauritius as a SIDS could consider the application of the SPI as a drought assessment tool for drought monitoring and disaster risk reduction, in the absence of temperature data for SPEI computations.

Keywords: drought; SPI; SPEI; global warming; R-programming; Pearson Correlation; Cohen's Kappa statistics; Bland-Altman plots; Mauritius.

Introduction

Drought had been part of the natural climate change cycle, and its effects were more severe in the past due to the absence of scientific definitions and monitoring systems (Jansen & Jonathan 2007).

The World Meteorological Organization (2024) defined drought as: 'A global hazard which formed part of the natural climatic cycle resulting in a prolonged dry period that could occur anywhere in the world'. It had also been defined to have a typically slow onset caused mainly by a lack of rainfall. The 6th assessment report, by the Intergovernmental Panel on Climate Change (IPCC 2021), urged global leaders to take decisive actions by emphasising on the following statement: 'An increase in the frequency, intensity and duration of droughts would increase risks of food security globally'. Therefore, in order to reduce the impact of droughts, an inter-regional workshop on drought indices and early warning systems was organised in December 2009 (Hayes et al. 2011). The aim of the workshop was to bring together participants in different countries across the world. During the workshop, the participants were tasked to review drought indices, currently in use in their particular countries, which could be useful to monitor meteorological, agricultural and hydrological droughts. The outcome of the workshop was published under the title *The Lincoln Declaration on Drought Indices* (Hayes et al. 2011) and it highlighted the needs for having a standard index that could be used to monitor different types of droughts. Experts recommended the application of the Standardised Precipitation Index (SPI) worldwide to monitor meteorological droughts. A comprehensive SPI user manual was also developed and approved in June 2011 at the sixteenth World Meteorological Congress.

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This study compared two strong drought indices, the SPI and its variant, the Standardised Precipitation Evapotranspiration Index (SPEI). It aimed to find the best index for meteorological drought monitoring in Mauritius, as a Small Island Developing State (SIDS), while also considering the impact of global warming on drought by applying the SPEI. The study also followed international guidelines for drought monitoring.

Literature review

Global warming and drought

Global warming, driven by the increased concentration of greenhouse gases in the atmosphere, had profound effects on the Earth's climate system, including the frequency and intensity of droughts. As global temperatures would continue to rise, precipitation and evaporation patterns across the globe would change drastically, hence increasing the probability of droughts (Trenberth et al. 2014). Warmer temperatures increased evaporation and water loss. In spite, warmer air could hold more moisture, which might suggest more rain, but it had been noticed that rainfall became uneven. Some places across the world suffered from droughts while others faced dangerous floods (IPCC 2021).

Global weather patterns changed due to global warming effects. Dry regions like the Mediterranean, southwestern United States, and parts of Australia had experienced drier climates. This was due to shifts in atmospheric circulation, like the Hadley cell, which moved rain-bearing storms further from the equator and reduced rainfall in these areas. As a result, the timing and reliability of wet seasons had also changed, making water storage and supplies more challenging (National Aeronautics and Space Administration [NASA] 2024).

Feedback loops in the climate system had further aggravated droughts under global warming effects. Severe droughts reduced vegetation, hence less carbon absorption, thus speeding up global warming. Dry soils and plants increased wildfire risks, releasing more greenhouse gases and further intensifying drought and warming (Allen et al. 2010). Agriculture sector, most commonly, suffered greatly from frequent and severe droughts due to insufficient steady water supply, hence, urging the needs to optimise towards drought-resistant crops and better irrigation systems in farming practices (World Bank 2017).

The ecological consequences of drought were also profound. Prolonged droughts had led to habitat loss, threatening the biodiversity of these areas. Aquatic species, in particular, were vulnerable to changes in water availability and quality. Furthermore, terrestrial ecosystems had suffered as plant and animal species struggled to survive in increasingly arid conditions. The stress on these ecosystems had led to reduced biodiversity and altered species composition, which had cascading effects on ecosystem services that humans relied

on, such as pollination, water purification and carbon sequestration (World Wildlife Fund 2020).

As a conclusion, global warming had significant effects on drought conditions through a complex interplay of increased evaporation, altered precipitation patterns and feedback loops. These changes had posed serious risks to agriculture, water resources and ecosystems, highlighting the urgent need for comprehensive strategies to mitigate and adapt to the impacts of climate change (Onaka et al. 2015). Addressing these challenges required global cooperation and the implementation of policies aimed at reducing greenhouse gas emissions, conserving water resources and protecting vulnerable ecosystems (IPCC2021).

Review of drought studies in Mauritius

Literature on the study of drought in Mauritius had remained low. Nowbuth and Saiboo (2009) analysed two catchments, Grand River South East and River Cascade of Grand River North West, to understand their response to the 1999 drought. They used various methods, including Flow Duration Curve, Low Flow Frequency Curves and Base Flow Index. Their results showed that the catchments responded effectively to the Run Sum Analysis method in predicting dry spells, hence for better water management in the island.

The study of Proag (2006) focused on water resources management in Mauritius. The author proposed three tiers of planning levels to come up with a Master Plan for the development of water resources in Mauritius. The author studied a section that was 'Reliability of Guaranteed Flow'. This section highlighted the importance of having a water storage system that could supply a constant flow of water as per demand. This section of the study also mentioned that in order to identify the limitations of constant flow by a water storage system, one should study the most severe case that was at least three consecutive drought periods. The study of Proag (2006) showed that a large reservoir with higher reliability (95%) was less vulnerable to severe drought than a reservoir with lower reliability of about (90%) or lower. Another important section in this study was the section on 'Public Awareness'. The author quoted the 1999 drought which affected Mauritius and classified it as a severe drought. He also stated that during that severe drought period in Mauritius, the public did not have sufficient information and guidelines of what to do and what not to do in such situations. In brief, the study of Proag (2006) brought up the importance of having an operational drought definition for the island so as to improve water management.

Dhurmea, Boojhawon and Rughooputh (2019) developed a high-resolution, multi-temporal drought climatology for Mauritius using the SPI based on rainfall data from 1953 to 2007. Their results showed SPI values ranging from +3.4 to -2.7, indicating extreme wet and dry conditions, with an increase in dry years after the 1990s. The SPI scale was adjusted for Mauritius' tropical-maritime climate and spatial

maps revealed mostly neutral to severely dry conditions, with some extreme wet and dry areas over the island. The cubic variogram model identified trends, showing extreme wet conditions mainly between 1972 and 1988. Short-duration wet events were more frequent on SPI-3 and SPI-6 time scales, while SPI-12 and SPI-24 showed similar wet and dry frequencies, though dry events lasted longer. The study of Dhurmea et al. (2019) was a first step in applying an existing drought index for drought assessment in Mauritius and analysing its historical trends.

The study of Seebocus, Lollchund and Bessafi (2021) analysed wet and dry conditions in Mauritius and suggested that climate change might be increasing extreme rainfall and drought events. The authors used statistical and fractal methods to study extreme precipitation and drought, by analysing monthly rainfall data from January 1950 to December 2016. They applied the generalised extreme value distribution to estimate 10-year return levels and 20-year return levels, which ranged from 500 mm – 850 mm and 600 mm – 1000 mm, respectively. The application of Standardised Precipitation Index (SPI) identified unusual wet and dry events, while a long-term correlation analysis examined the link between maximum rainfall and its duration. Their results showed that extreme rainfall mostly occurred during austral summer (November–April), likely due to tropical cyclones, while prolonged droughts were linked to La Nina phases. This study helped understanding the main causes of drought in Mauritius.

Doorga (2022) conducted a study on the impacts of climate change on small island states. His study revealed that between the period 1971 and 2020, the warming rate in Mauritius was $0.0216\text{ }^{\circ}\text{C}/\text{year}$ and rainfall was found to experience an increase of $2.29\text{ mm}/\text{year}$. The study by Doorga (2022) also found that climate change had severely affected the island's native ecosystems and threatened its long-term freshwater supply. To address this, he suggested two solutions. Firstly, he proposed science-based policies to redesign protected areas in climate-resilient regions, helping native plants and animals. Secondly, he recommended improving freshwater resilience by introducing a coordination system based on water stress levels and expanding freshwater catchment networks in areas with increasing rainfall.

In contrast to the study of Doorga (2022), Nussaibah and Olgu (2019) analysed rainfall variability and trend over a 30-year period (1981–2010) across 53 meteorological stations in Mauritius. Their results showed an increasing trend in the annual rainfall in Mauritius. Statistical tests (Mann-Kendall and Spearman's rho) showed both increasing and decreasing trends. However, rainfall decreased between 1996 and 2000 due to a moderate La Nina event (1998–2000), resulting into a drought, aligning with the findings of Seebocus et al. (2021). Overall, the study found an increase in rainfall over time, linked to more extreme rainfall events in the region, which was similar to the findings of Dhurmea et al. (2019).

Review of Standardised Precipitation Index

The SPI was first introduced by Mckee, Doesken and Kleist (1993). The initial approach was to create a basic index using a single variable, such as precipitation values, to track drought by providing insights into its intensity, frequency and duration. In order to make this attempt, Mckee et al. (1993) started by using standardised precipitation. It was simply the difference of precipitation from the mean divided by the standard deviation where the mean and standard deviation were determined from past records of precipitation data. The technique of standardised precipitation relied strongly on a normally distributed precipitation pattern. Therefore, the standardised precipitation values were then transformed to fit a mathematical standard distribution such as Gamma, Poisson and Logarithmic distributions. This transformation was important to make the standardised precipitation values linearly proportional to precipitation deficit values. Mckee et al. (1993) adopted the Gamma distribution to transform and fit the standardised precipitation values in the SPI computations such that the mean of all values was zero and had a standard deviation value of one. Because the SPI values were normally distributed, they were able to monitor both wet and dry periods. The SPI also worked well with variables such as snow, reservoir levels, streamflow, soil moisture and ground water. The conclusion obtained from SPI time series plots at different time scales by Mckee et al. (1993) was that when the time periods were small (3 or 6 months), the SPI graphs moved frequently above and below zero. As the time period was lengthened to 12, 24 and 48 months, the negative and positive variations became fewer in number but longer in duration. Mckee et al. (1993) also concluded that a drought event would occur when the SPI values were continuously negative after reaching a magnitude of -1.00 or less and would end when the SPI values became positive. The drought intensity based on SPI values by Mckee et al. (1993) had been summarised in Table 1. At the same time, the drought magnitude (DM) could be obtained by taking the positive sum of consecutive periods when the SPI values had dropped to -1.00 and less until its first positive value.

The application of SPI had been used in several studies. The study of Agwata (2014) reviewed different meteorological drought indices and made a systematic selection approach of their strengths and weaknesses. He also based his selection

TABLE 1: Standardised Precipitation Index categories.

SPI values	Drought categories
+2.00 and more	Extremely wet
+1.50 to +1.99	Very wet
+1.00 to +1.49	Moderately wet
-0.99 to +0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.00 and less	Extremely dry

Source: McKee, T.B., Doesken, N.J. & Kleist, J., 1993. 'The relationship of drought frequency and duration to time scales,' in *Proceedings of the 8th Conference on Applied Climatology*, American Meteorological Society, Boston, MA, January 17–221, 1993, pp. 179–184; Svoboda, M., Hayes, M. & Wood, D., 2012, *Standardized precipitation index user guide*, WMO-No 1090, World Meteorological Organisation, Geneva

SPI, Standardised Precipitation Index.

on the ability of the index to give appropriate information on the drought magnitude, duration and severity. The author used the base drought classes defined by Mckee et al. (1993) to adopt a new drought class with respect to the area of study. His proposed drought classes were as follows: (1) SPI values less than -1.65 were classified as extreme drought; (2) less than -1.28 were severe drought; (3) less than -0.84 moderate drought; and (4) less than -0.05 no drought. The study of Agwata (2014) showed that the SPI classes defined by Mckee et al. (1993) could be modified to adapt to different geographical locations.

In another similar study to evaluate the versatility of the SPI, Hayes and Alvord (2007) reviewed five drought indices including the SPI. The authors highlighted the strengths and weaknesses of each index. They found that the SPI was based on the probability of precipitation for any time scale and due to this advantage, it could be computed for different time scales. As a result, the SPI could provide an early warning of drought and also help in the severity assessment of the drought event because the positive sum of the SPI values for each month during the drought event would give the drought magnitude as stated by Mckee et al. (1993). The authors also found that the SPI was less complex than other indices that they reviewed in their study.

In the study of Quiring (2009), in which the authors aimed to develop an objective operational definition for drought monitoring, they concluded that the SPI's flexibility over time could help monitor various types of droughts, including meteorological, hydrological and agricultural droughts. They also highlighted that the SPI could be applied in different climatic regions except for arid regions with precipitation values often zero. In spite of the versatility of the index and its applications, there are some limitations that should be considered while applying the SPI. These limitations, which had been highlighted in literature reviews, were as follows:

- The length of precipitation record was important for SPI calculations (Guttman 1998, 1999).
- The effectiveness of the index was strongly dependent on the probability distribution technique to transform the standardised precipitations (Mckee et al. 1993; Mishra & Singh 2010).
- It used precipitation as the sole input. Therefore, the effects of temperature and evaporation rate were not considered, which could be an important component for taking into consideration the influence of global warming (Vicente-Serrano, Beguería & López-Moreno 2010).

Review of Standardised Precipitation Evapotranspiration Index

The SPEI could be considered a relatively new drought index. It had been developed in Spain by Vicente-Serrano et al. (2010). The SPEI used the basis of SPI but included a temperature component, allowing the index to account for the effect of global warming on drought through a basic water balance calculation known as the potential

evapotranspiration (PET). The methodology to compute PET was initiated by Thornwaite (1948) in his study of climate classification. Then another method was introduced by Penman and the detailed steps for the calculation were published in 2014 by a group of researchers from the University of Florida (Zotarelli et al. 2014). Finally, the Hargreaves method was also developed and had been recently used in a study in Texas for estimating crop evapotranspiration (Hargreaves 1994). The Thornwaite (1948) method had proved to be simpler than the other methods for PET calculations, which required only two variables for its computation. Finally, an algorithm in R – *programming* was made available for calculating the SPEI from user-selected input data using either the Thornwaite, Penman-Monteith or Hargreaves methods. Similar to the classification of SPI in Table 1, SPEI used an intensity scale with both positive and negative values to identify wet and dry events from 1 to 48 months. By incorporating temperature along with rainfall data, SPEI accounted for temperature effects on drought conditions. However, like all drought indices, it had limitations, including the need for a complete dataset of both temperature and precipitation, which could restrict its use. Additionally, as a monthly index, it might not detect rapidly developing droughts (Begueria et al. 2014; Vicente-Serrano et al. 2010).

Review of Standardised Precipitation Index or Standardised Precipitation Evapotranspiration Index comparative studies

Comparative studies between the application of SPI and SPEI drought indices had been reviewed in different parts of the world.

The first reviewed case was in Ethiopia. The study was conducted by Tefera, Ayoade and Bello (2019). In this study, the authors compared the SPI values and its variant the SPEI. The authors concluded that, as drought assessment tools, SPI and SPEI showed a medium to high level agreement across one, three, six, twelve, and 24 months' time scales. The authors evaluated this agreement using Cohen's Kappa statistics and the Bland-Altman method, applied to gridded monthly rainfall and temperature data from the Climatic Research Unit for the period 1901 to 2016. The study concluded that in the absence of temperature data for the calculation of SPEI, the SPI alone could be used as a drought monitoring tool in the region of Ethiopia. The authors also brought forward that the lack of literature on their methodologies in their study would require that such studies could be conducted in other parts to strengthen their findings.

Another study on drought indices comparison was performed by Mostafazadeh and Zabihi (2016). This study compared historical droughts using SPI and SPEI with R programming, selecting SPEI for its ability to capture multi-scale droughts. Due to limited data (1995–2013), seven synoptic stations in Kurdistan Province were analysed. Standardised Precipitation Index was calculated using gamma distribution, while SPEI incorporated temperature effects via Thornthwaite's

equation. Their results showed that SPI and SPEI correlations ranged from 0.19 to 0.52 ($p < 0.01$), with one station showing low correlation due to high evaporation in warmer months. The authors recommended SPEI over SPI as it captured longer and severe droughts in arid regions. The authors also suggested using Thornthwaite's method for PET calculations and called for similar studies to be conducted in countries of different climate regimes.

The next comparative study was conducted in the temperate climate of Canada. Gurrapu et al. (2014) compared SPI and SPEI, as both indices identify droughts over different time scales. Analysis of meteorological stations across Canada and the prairie region showed that 20th-century droughts were detected by both indices. However, due to low temperature variability, differences between SPI (precipitation-based) and SPEI (temperature-influenced) were minimal. When temperatures rose by 2 °C to 4 °C, SPEI showed more severe and prolonged droughts, making it a better tool for assessing 21st-century droughts with expected warming. The study also found SPEI useful for tracking streamflow variability in western Canada's natural rivers.

Another comparative study of SPI and SPEI drought in temperate climate was performed in Turkey by Oksal (2023). The study examined temperature effects on drought in Turkey's Marmara region using SPEI. Standardised Precipitation Index and SPEI were analysed over periods of 3-months, 6-months and 12-months to assess spatial and temporal drought patterns. The results showed SPEI droughts lasted longer and were more intense due to rising evapotranspiration from higher temperatures. Standardised Precipitation Index and SPEI had a strong correlation, but SPI recorded more extreme droughts, while SPEI showed more severe and moderate droughts. The most severe drought years identified in Turkey were 1989, 1990, 2001, 2007, and 2014. The study of Oksal (2023) also concluded that temperature should be considered for drought monitoring in their region.

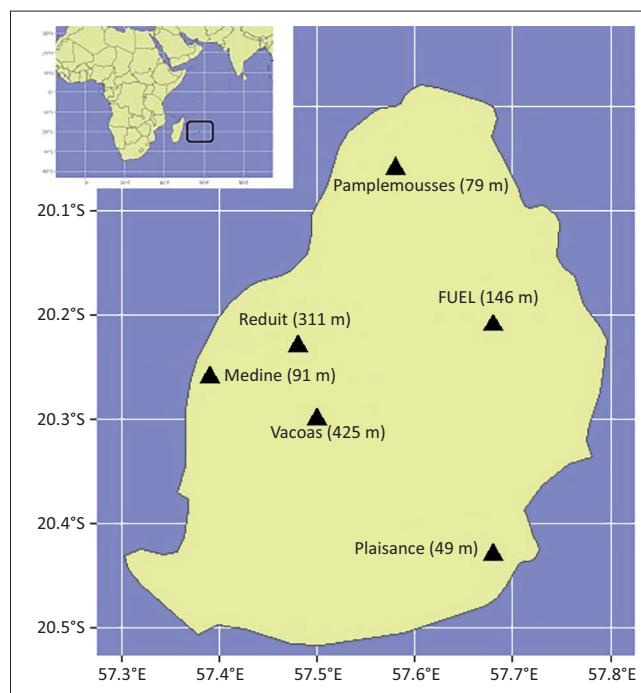
After reviewing SPI and SPEI in temperate climatic regions, the case of Bangladesh, mostly with a tropical climate regime, had been studied by Akter et al. (2023). This study analysed drought trends between 1979 and 2020, SPI-SPEI comparisons and predictions in Rangpur, Bangladesh. Modified Mann-Kendall assessed trends, while Pearson Correlation and Linear Regression evaluated SPI-SPEI relationships. Artificial Neural Network (ANN), Support Vector Machine (SVM) and Random Forest (RF) were used for predictions. The results of Akter et al. (2023) showed notable negative drought trends, with SPI and SPEI correlations peaking at 97% – 98%. Standardised Precipitation Evapotranspiration Index outperformed SPI in accuracy. Artificial Neural Network predictions indicated SPEI-3 and SPEI-6 would rise by 0.02 and 0.24, respectively, for short-term droughts, but long-term forecasts were unreliable. The study highlighted the need for better predictive tools for future drought assessment.

A similar study was also conducted in Chile by Meseguer-Ruiz et al. (2024). The study showed that Chile's varied climate, due to its latitude and terrain, led to differences in rainfall, temperature and drought severity. Using CR2Met 5 × 5 km gridded data (1979–2019), the authors calculated SPI and SPEI for March and September, at 3- to 24-month scales, to analyse climate patterns and trends. Their results showed weak SPI correlations with the Pacific Decadal Oscillation (PDO), while El Niño and Antarctic Oscillation influenced both SPI and SPEI in northern Chile. Drier trends appeared in the north and centre, while wetter trends were observed in the south, with SPEI showing stronger negative trends due to rising temperatures. Standardised Precipitation Index suited coastal areas, where warming was lower, while SPEI was better for inland regions. These findings aimed to support water management decisions in Chile.

Research methods and design

Study area and data

Mauritius is an island nation in the Indian Ocean, located about 850 kilometres east of Madagascar. Its geographic coordinates ranged between latitudes 19°58.8 and 20°31.7 South, and longitudes 57°18.0 and 57°46.5 East (Maps of the World 2024). The Republic of Mauritius encompassed several islands, including Rodrigues, Agalega, St. Brandon (Cargados Carajos Shoals), Tromelin, and the Chagos Archipelago, including Diego-Garcia. However, the sovereignty of the Chagos Archipelago was a subject of dispute. In October 2024, the United Kingdom agreed to transfer control of the Chagos Islands to Mauritius, while retaining a 99-year lease over Diego Garcia for military purposes (Colchester 2024).



Note: Created using R-Package 'rnatuarearth' (v1.0.1).

FIGURE 1: Map of Mauritius with selected rainfall and temperature stations for the study.

The area of the main island, Figure 1, was approximately 1865 km².

For this study, data for six stations were selected as shown in Figure 1. Each station was assumed to represent rainfall and temperature over an area of radius five kilometres horizontally, covering the main surface water reserves, river basins, natural forests, vegetation and populated areas. Data were collected from the Hydro-Meteorological and Climatology sections at the headquarters of the Mauritius Meteorological Services, situated at Vacoas. The methodologies of McGill, Tukey and Larsen (1978), Williamson (1989), Steel et al. (2013) and Nuzzo (2016) which consisted of boxplot interpretations were referred to for data cleaning. Monthly rainfall and temperature values at all the stations were averaged to represent the whole island of Mauritius (Figure 2).

Methodology

This study adopted research techniques from previous drought studies, prioritising their application in Mauritius. Rising water demand and economic growth, particularly in tourism, made drought research essential.

Standardised Precipitation Index

Standardised Precipitation Index was calculated using the methodologies of Mckee et al. (1993), Svoboda, Hayes and Wood (2012), Guttman (1999), and Dhurmea et al. (2019). The general formula for SPI calculation was as follows (Equation 1):

$$SPI = \frac{(X - \mu)}{\sigma} \quad [\text{Eqn 1}]$$

where, X represented as observed monthly precipitation value,

μ , long-term mean of precipitation from 1981 to 2010,

σ was the standard deviation of precipitation for the same time scale.

The following methods were adopted for SPI calculation:

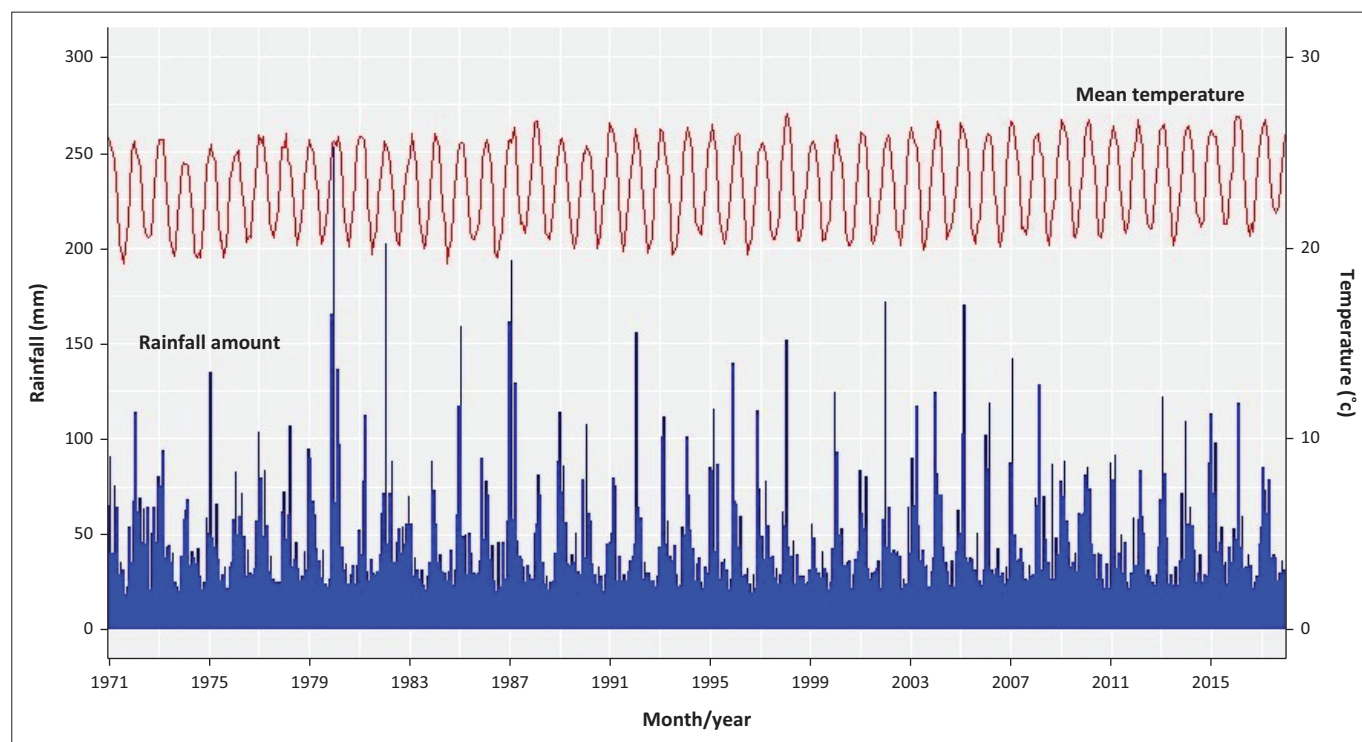
- Monthly rainfall data between the period of 1971 and 2017 were prepared and fitted with gamma distribution, using SPEI package in *R – Programming*.
- SPI data series at 1-month, 3-months, 6-months, and 12-months were generated.
- Positive (Wet) and negative (Dry) rainfall patterns were generated using ggplot2 package from *R – programming*.
- Drought periods were identified and classified using the classification criteria defined in Table 1 by Mckee et al. (1993), Svoboda et al. (2012).

Standardised Evapotranspiration Precipitation Index

Standardised Precipitation Evapotranspiration Index methodology was based on the works of Hargreaves (1994), Droogers and Allen (2002) and Vicente-Serrano et al. (2010). The steps for SPEI were similar to SPI except that maximum and minimum temperature data were required in the calculation.

Pearson's correlation coefficient (r)

Pearson correlation was applied to measure the degree of correlation between the SPI and SPEI values. This method was applied because of its ease of use and simple result output using *R – Programming*. The mathematical expression for the Pearson Correlation Coefficient, denoted by r , between



Note: Created Using: R-Package 'ggplot2' (v1.8.1) from Data: Mauritius Meteorological Services.

FIGURE 2: Annual rainfall and temperature variability in Mauritius.

SPI and SPEI was represented by two variables, X and Y respectively (Equation 2):

$$r = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2 \sum (Y_i - \bar{Y})^2}} \quad [\text{Eqn 2}]$$

where;

- X_i and Y_i were individual data point in the datasets for variables X (SPI) and Y (SPEI) respectively,
- \bar{X} and \bar{Y} were the means (averages) of the datasets for variables X (SPI) and Y (SPEI) respectively,
- The numerator represented the covariance between X (SPI) and Y (SPEI), which measured the joint variability of the two variables.
- The denominator was the product of the standard deviations of X (SPI) and Y (SPEI), which represented the individual variability of each variable.
- The correlation coefficient r ranged from -1 to $+1$, such that:
 - $r = 1$ indicated a perfect positive linear relationship between SPI and SPEI values.
 - $r = -1$ indicated a perfect negative linear relationship between SPI and SPEI values.
 - $r = 0$ indicated no linear relationship.

Cohen's Kappa statistics

Cohen's kappa statistic was applied to SPI and SPEI values to measure agreement between the two methods in their calculation, using *R – Programming*. This method was selected because it provided a more accurate reliability assessment than simple percent agreement (Cohen 1960; Landis and Koch 1977). It ranged from -1 (systematic disagreement) to $+1$ (perfect agreement), with 0 indicating chance-level agreement. Kappa values above $+0.75$ signified excellent agreement, $+0.40$ to $+0.75$ indicated fair to good agreement, and below $+0.40$ suggested poor agreement, as shown in Table 2.

Cohen's kappa statistic (κ) was calculated using the following formula (Equation 3):

$$\kappa = \frac{P_o - P_e}{1 - P_e} \quad [\text{Eqn 3}]$$

where:

- P_o was the observed agreement between the two raters (SPI and SPEI).
- P_e was the expected agreement by chance.

TABLE 2: Interpretation of Cohen's Kappa.

Kappa value*	Level of agreement
< 0	Less than chance agreement
0.01–0.20	Slight agreement
0.21–0.40	Fair agreement
0.41–0.60	Moderate agreement
0.61–0.80	Substantial agreement
0.81–1.00	Almost perfect agreement

Source: Cohen, J., 1960, 'A coefficient of agreement for nominal scales', *Educational and Psychological Measurement* 20(1), 37–46. <https://doi.org/10.1177/001316446002000104>; Landis, J.R. & Koch, G.G., 1977, 'The measurement of observer agreement for categorical data', *Biometrics* 33(1), 159–174. <https://doi.org/10.2307/2529310>

*. Significant at $p < 0.01$.

Bland-Altman plot

Bland-Altman plots, also known as difference plots, were a graphical method used to analyse the agreement between SPI and SPEI values. This method, introduced by Bland and Altman (1986), was particularly useful for comparing two methods or instruments that measured the same parameter. This graphical approach complemented statistical tests by providing a visual assessment of agreement, making it a robust tool for method comparison studies (Giavarina 2015). Bland-Altman plots were generated in *R – Programming* by following these steps, where X was substituted by SPI and Y by SPEI:

1. Calculate the differences between the two measurements for each subject (Equation 4):

$$d_i = X_i - Y_i \quad [\text{Eqn 4}]$$

where X_i and Y_i are the measurements from the two different methods for subject i which were SPI and SPEI.

2. Calculate the average of the two measurements for each subject (Equation 5):

$$\bar{M}_i = \frac{X_i + Y_i}{2} \quad [\text{Eqn 5}]$$

3. Plot the differences (d_i) on the y-axis against the averages (\bar{M}_i) on the x-axis.
4. Calculate the mean difference (bias) (Equation 6):

$$\bar{d} = \frac{1}{n} \sum_{i=1}^n d_i \quad [\text{Eqn 6}]$$

5. Calculate the standard deviation of the differences (Equation 7):

$$s_d = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (d_i - \bar{d})^2} \quad [\text{Eqn 7}]$$

6. Calculate the limits of agreement, which were typically set at ± 1.96 times the standard deviation of the differences:

$$\text{Upper limit of agreement} = \bar{d} + 1.96 \cdot s_d$$

$$\text{Lower limit of agreement} = \bar{d} - 1.96 \cdot s_d$$

These limits were then plotted as horizontal lines on the Bland-Altman plot.

Ethical considerations

This article does not contain any studies involving human participants performed by any of the authors.

Results and discussions

Standardised Precipitation Index and Standardised Precipitation Evapotranspiration Index analysis

Figure 3 shows SPI and SPEI time series at 1-month, 3-months, 6-months, and 12-months timescales. The figure highlights the extreme rainfall variability in Mauritius with alternate wet and dry periods.

Similarities of standard error (s.e.) and standard deviation (s.d.) values from Table 3 show that both SPI and SPEI are reliable for drought monitoring in Mauritius. In addition, both indices indicate that the year 1999 was the worst drought in Mauritius. However, by referring to the minimum (Min) and maximum (Max) values, it can be deduced that SPEI is more responsive to dry situations than SPI, due to its sensitivity to temperature, making it more reliable in drought assessments.

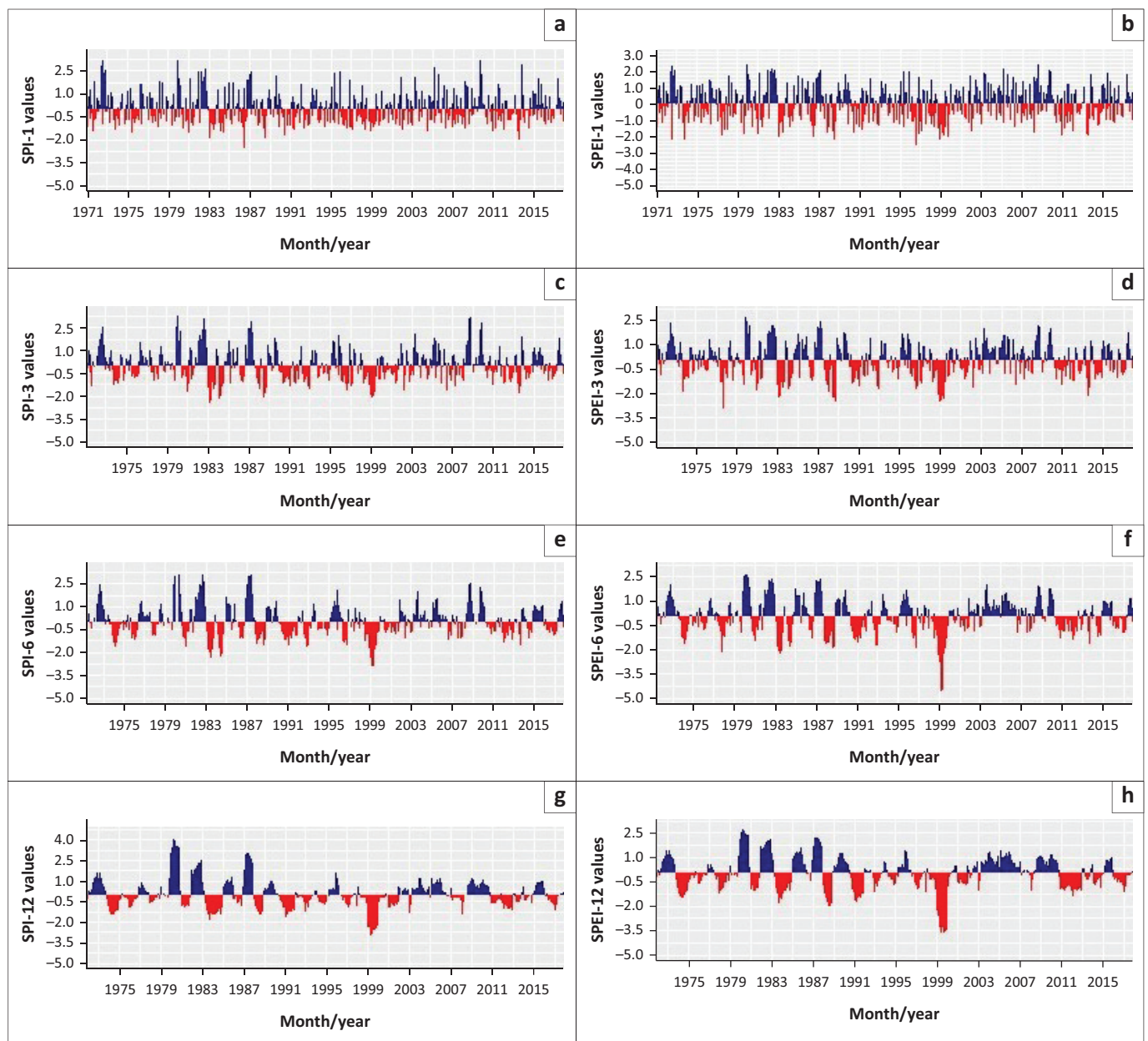
Linear Pearson correlation plots

Pearson's correlation coefficient between SPI and SPEI shows strong and significant relationship at all timescales with the following parameters: ($r = 0.94$, $p < 0.01$).

Additionally, the scatter plot diagrams in Figure 4 reveal good positive linear relationship ($R^2 > 0.57$). The strong correlation values support the previous statistical findings, confirming that both SPI and SPEI are suitable for drought monitoring in Mauritius.

Bland-Altman plots

The narrow limits of agreement (lowerlimit = Bias-1.96*s.d., upperlimit = Bias+ 1.96*s.d.) across all examined time scales, as shown in Figure 5, indicate a strong level of consistency between SPI and SPEI. Hence, the Bland-Altman plots further strengthen the statement that both indices provide comparable assessments for drought in Mauritius.



Note: Created Using: R-Package 'ggplot2' (v1.8.1) from Data: Mauritius Meteorological Services. SPI, Standardised Precipitation Index; SPEI, Standardised Precipitation Evapotranspiration Index.

FIGURE 3: Comparing Standardised Precipitation Index and Standardised Precipitation Evapotranspiration Index. a, SPI 1-month; b, SPEI 1-month; c, SPI 3-months; d, SPEI 3-months; e, SPI 6-months; f, SPEI 6-months; g, SPI 12-months; h, SPEI 12-months.

TABLE 3: Summary statistics for Standardised Precipitation Index and Standardised Precipitation Evapotranspiration Index at different time scales for the period 1971–2017.

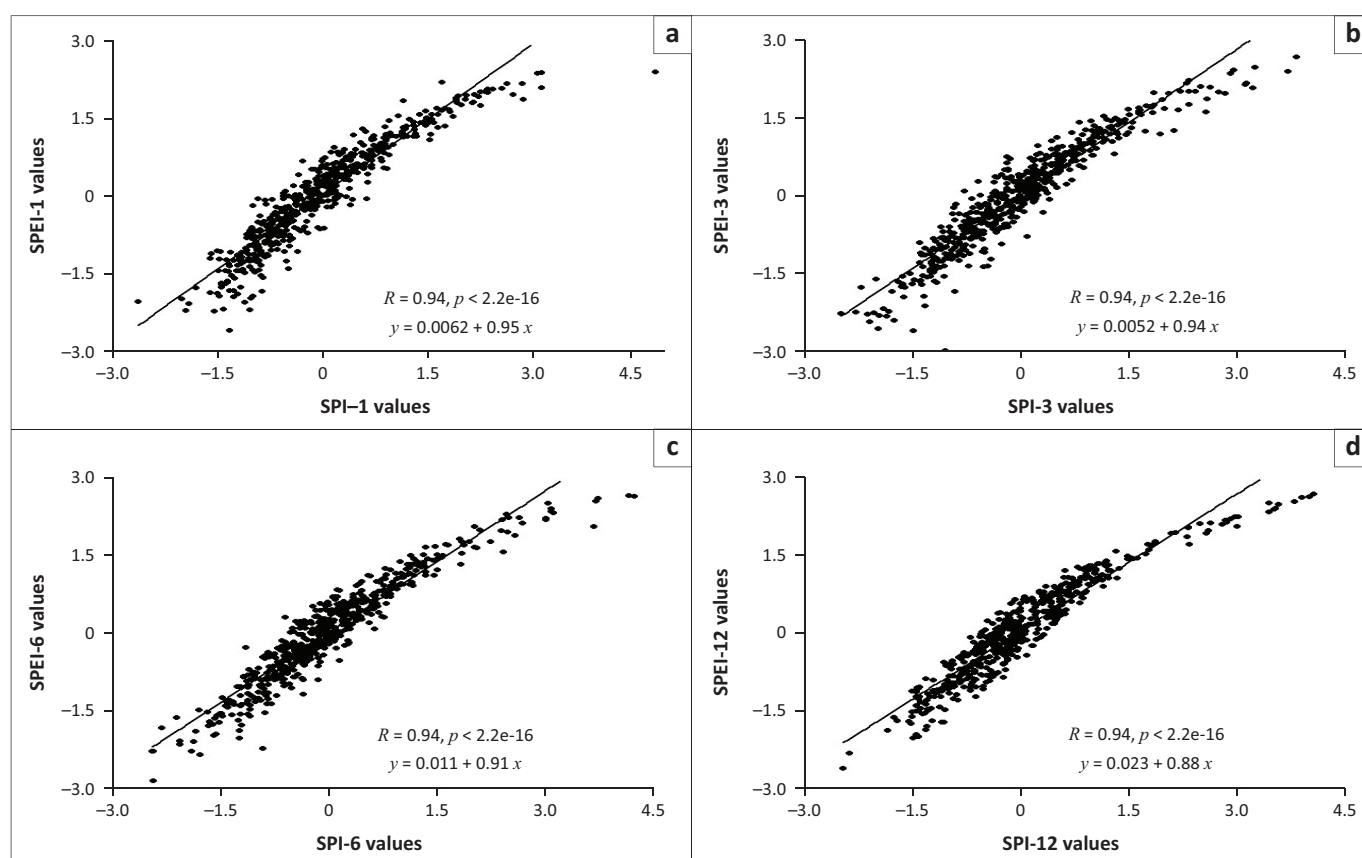
Time scale (month)	Index	Mean	s.e.	s.d.	Min†	Year†	Max‡	Year‡
1	SPI	0.0053	0.0409	0.9703	-2.62	1986	+4.86	2008
	SPEI	-0.0036	0.0441	1.0360	-3.01	1999	+2.41	2008
3	SPI	0.0005	0.0419	0.9939	-2.47	1983	+3.81	1980
	SPEI	0.0057	0.0418	0.9916	-2.98	1977	+2.67	1980
6	SPI	-0.0029	0.0431	1.0197	-2.92	1999	+4.21	1980
	SPEI	0.0001	0.0427	1.0099	-4.65	1999	+2.65	1980
12	SPI	-0.0036	0.0441	1.0360	-3.01	1999	+4.06	1980
	SPEI	0.0012	0.0432	1.0151	-3.65	1999	+2.66	1980

Note: Summary of statistics compiled from data collected at the Mauritius Meteorological Services between 1971 and 2017. Computed Using R-4.4.1 from Data: Mauritius Meteorological Services.

SPI, Standardised Precipitation Index; SPEI, Standardised Precipitation Evapotranspiration Index; s.e., standard error; s.d., standard deviation.

†, Absolute Minimum Value obtained from SPI and SPEI calculations and the Observed Year.

‡, Absolute Maximum Value obtained from SPI and SPEI calculations and the Observed Year.



Note: Created Using: R-Package 'ggplot2' (v1.8.1) from Data: Mauritius Meteorological Services.

SPI, Standardised Precipitation Index; SPEI, Standardised Precipitation Evapotranspiration Index.

FIGURE 4: Linear correlation plots between Standardised Precipitation Index and Standardised Precipitation Evapotranspiration Index. a, 1-month; b, 3-months; c, 6-months; d, 12-months.

Conclusion

This study assessed the agreement between SPI and SPEI at 1-month, 3-months, 6-months, and 12-months timescales using Pearson's correlation, Bland-Altman analysis and Cohen's Kappa statistics.

The summarised results in Table 4 indicate strong agreement across all examined timescales, with a consistent Pearson Correlation Coefficient of 0.94, highlighting a strong linear relationship. The findings also conclude that SPI can substitute SPEI when temperature data or calculation tools are unavailable, making it a practical choice for drought

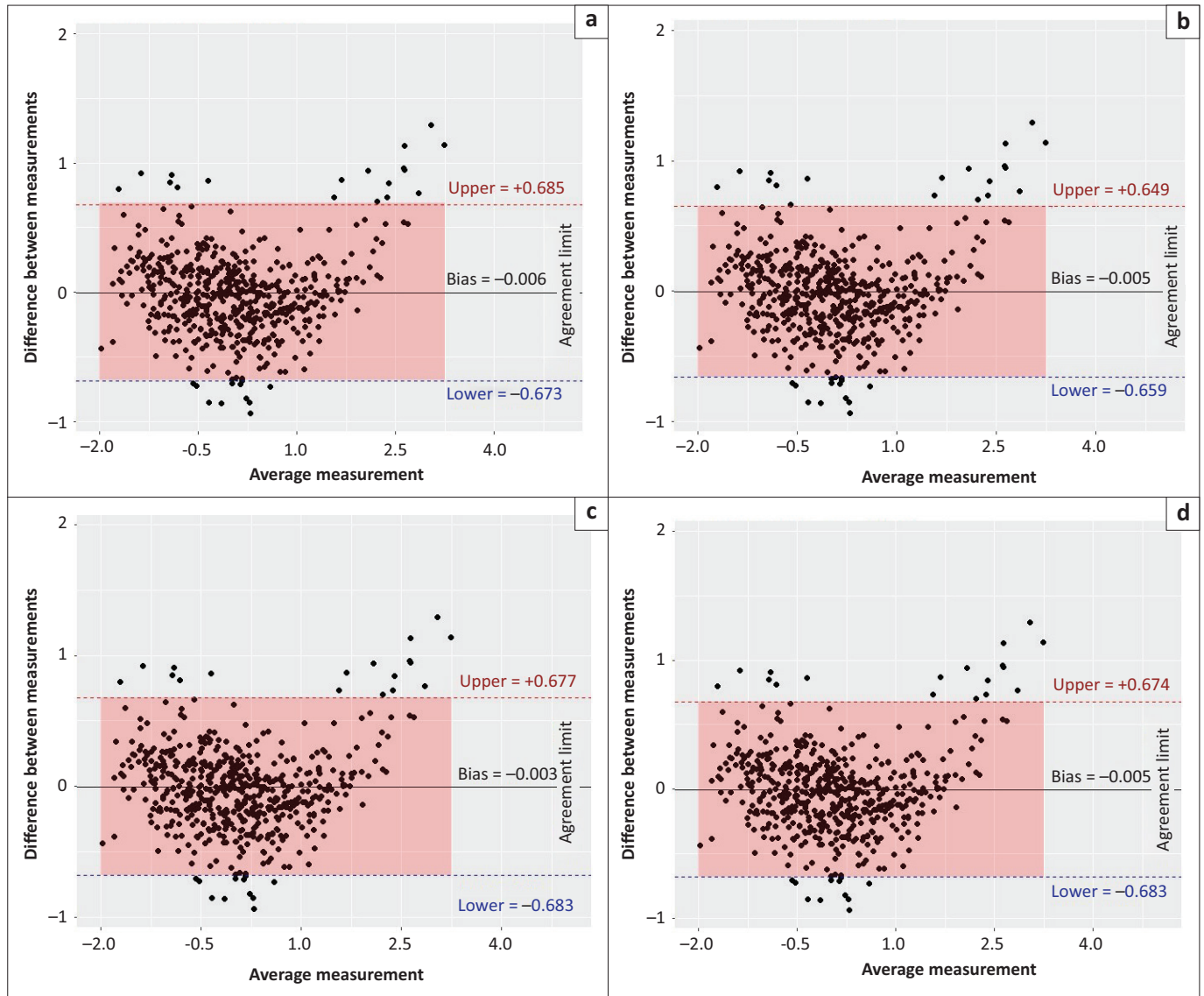
TABLE 4: Summary of agreement tests between Standardised Precipitation Index and Standardised Precipitation Evapotranspiration Index.

Timescale (month)	Kappa*	Pearson (r)**	Bland-Altman (Range)
1	0.94	0.94	Upper = +0.685, Lower = -0.673
3	0.95	0.94	Upper = +0.649, Lower = -0.659
6	0.94	0.94	Upper = +0.677, Lower = -0.683
12	0.94	0.94	Upper = +0.674, Lower = -0.683

Note: Computed Using R-4.4.1 from Data: Mauritius Meteorological Services.

*, **, Test significant at ($p < 0.01$).

monitoring in Mauritius. The SPI classification system by Mckee et al. (1993) and Svoboda et al. (2012) effectively identified extreme wet and dry events in Mauritius, validating



Note: Created Using: R-Package 'ggplot2' (v1.8.1) from Data: Mauritius Meteorological Services. SPI, Standardised Precipitation Index; SPEI, Standardised Precipitation Evapotranspiration Index.

FIGURE 5: Bland-Altman plots between Standardised Precipitation Index and Standardised Precipitation Evapotranspiration Index. a, 1-month; b, 3-months; c, 6-months; d, 12-months.

its applicability. Therefore, Mauritius can adopt Mckee et al. (1993)'s drought threshold, where a drought begins when SPI falls below -1.00 and remains negative, ending with the first positive SPI value. While SPEI is preferred for its inclusion of evapo-transpiration, SPI remains a reliable alternative.

Further research can investigate the performance of alternative drought indices, as described by Svoboda et al. (2012), to determine their applicability in Mauritius. Additionally, this can enhance drought detection accuracy and improve early warning systems. Comparative studies assessing the sensitivity of SPI and SPEI under future climate change scenarios can provide insights into their long-term reliability. Furthermore, exploring the role of soil moisture, vegetation indices, and remote sensing data in drought assessment could offer a more comprehensive understanding of drought dynamics in the region.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

V.M., as PhD student, has contributed to the conceptualisation, methodology, formal analysis, investigation, software and writing of the first draft of the article. M.D.N., as main project supervisor, has contributed to supervision, validation, data curation, resources, reviewing and editing.

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Data availability

Data have been retrieved by writing a formal letter of request to have data access from the Head of the Mauritius Meteorological Services.

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