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Comparative analyses of SPI and SPEI as drought characterization tools in Massili watershed, central Burkina Faso

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ABSTRACT

Assessment of hydrological drought indices in drought prone areas provides useful information for accurate and sustainable water resources management. However, meteorological drought estimation in ungauged basin remains less studied. The main objective of this study was to compare the ability of Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) to reproduce historiological drought within Massili basin. To this end, monthly historical rainfall and temperature time series spanning from 1960 to 2021 have been collected from the national agency of meteorology. R programming language has been applied to display Boxplots in order to identified the temporal dispersion of the rainfall indices. Then the Spearman correlation was applied to illustrate the relationships between the SPEI and the SPI. The results shows that both SPEI and SPI exhibit consistent behavior in observed drought within the Massili watershed. Dry conditions prevailed during the period 1980–1990, 1990–2000 and 2000-2010. Severe wet conditions prevailed in years 1984, 1985,1998 and 2002. In all time scale the SPEI and SPI are characterized by high correlation. The Spearman correlation coefficients value is above 0.7 with the highest correlation value detected between SPEI-24 and SPI-24 (0.97). This study may contribute to better understand the drought patterns within the basin for water resources planning perspectives.

Contribution/Originality: This paper compares the ability of SPEI and SPI to reproduce drought within Massili basin. To the best of our knowledge, this paper is the first to compares the ability of SPEI and SPI within Massili basin.

1. INTRODUCTION

Global warming is expected to substantially impact weather patterns. It is widely accepted that an increase of the Earth's mean temperature up to 1.5°C will result in frequents occurrence of extreme weather events such as droughts, heat waves and floods [1-3]. According to Sheffield and Wood [4] drought is a deficit of water relative to normal conditions. Zargar, et al. [5] stated that drought is a natural hazard caused by intense and persistent precipitation deficiency. Therefore, drought can be referred to a deficiency in rainfall, soil moisture, streamflow and socioeconomic conditions [6-8]. At global scale, this creeping phenomenon figure out to be the costliest and least understood extreme natural event jeopardizing living sectors such as agriculture, water supply, health ecosystem [9-

11]. Over the past century, more than 642 drought events were recorded worldwide with around 12 million people killed, economic damages were estimated at USD 135 billion and nearly 2 billion people was affected by this disaster [12]. Therefore, drought has significant negative impacts on agricultural productivity, environment and food security [13]. Indeed, as stated by Bielders, et al. [14], drought leads to the loss of the soil's productive capacity which is a great concern to the local people mainly subsistence farmer. Prolonged drought events characterized by a general reduction in the amount of precipitation has happened in West Africa over past decades [15]. The United Nations Development Program (UNDP) [16] classified Burkina Faso as the 5th most disadvantaged country in the world. This low-income country has experienced severe drought during the period 1970s and 1980s with hugue socio-economic losses, mainly in agricultural sector. Moreover, from 1970 to 1990, around 17 drought events were recorded within the country with 7.038.290 people affected. Four main drought classes based on their characteristics and outbreaks can be found in the litterature. Hydrological drought can be defined as a deficit of water in hydrological processes with a repercussion in water bodies. Climatological or meteorological drought is related to the magnitude of a precipitation shortfall and the persistence of this change. Agricultural drought however links the various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, and soil moisture deficits. According to Mehran, et al. [17] socioeconomic drought is associated with the supply and demand of some economic good with elements of meteorological, agricultural, and hydrological drought. A growing number of studies have focused on drought issues in Burkina Faso. Ruelland, et al. [18] used aerial photographs and satellite images to show the implication of droughts events on land degradation. Kasei, et al. [19] investigated temporal characteristics of climatological droughts in the Volta basin using the standardized precipitation index (SPI). They found that the drought intensity is lower than −2.0 in 75% of the study area. A drought index is defined as a number used to determine the magnitudes of drought events. Various drought indicators can be found in the literature. For instance, Van Rooy [20] developed the Integrated Drought Index (IDI) which is based on meteorological, hydrological, and agricultural droughts. The Rainfall Anomaly Index (RAI) was introduced by Byun and Wilhite [21] to depict meteorological drought by computing positive precipitation anomalies and negative precipitation anomalies. The Effective Drought Index (EDI) developed by McKee, et al. [22] which stand to be the only index introduced to calculate daily drought severity. Under the EDI analysis, extreme drought occured when EDI is less than -2, severe drought refers to an EDI value ranging between -2 and -1.5, and moderate drought show an EDI between -1.5 and -1.0. Near normal conditions are indicated by EDI between -1 and 1.0. the Standardized Precipitation Index (SPI) was introduced by McKee, et al. [23] and allow to evaluate the impact of precipitation deficit on water sources using standardized precipitation. The main objective of this study is to compare the drought patterns in Massili basin based on SPEI and SPI. As stated by Hao and AghaKouchak [24], knowledge of drought patterns at local scale is useful for adaptation perspectives. However, lack of proper information about the spatiotemporal characteristics of droughts may lead to poor decision-making that results in additional drought-related costs and damages [25]. Thus, the motivation for this paper stems from the increasing needs for drought related information to address water management issues.

2. MATERIAL AND METHODS

2.1. Study Area

Massili watershed (1°15'W -1°55' W; 12°17'N-12°50'N) is a sub-basin of the Nakambe which is a tributary of the Volta River. The study area is 2612 km^2 (Figure 1). Massili basin's climate is influenced by the monsoon occurring during May to September and the Harmattan. Mean annual precipitation ranges from 700 to 900 mm/year and the country records one rainy season lasting from June to September. The annual maximum and minimum temperatures varied from 27.8 to 33.7 and 14.4-23.7°C, respectively. Analysis of the land cover types shows that 27% of the basin is covered by tree and shrub savannas while agricultural landscapes engulf 59% of the territory. The relief is generally low and dominated by plain with elevation not exceeding 3500m.

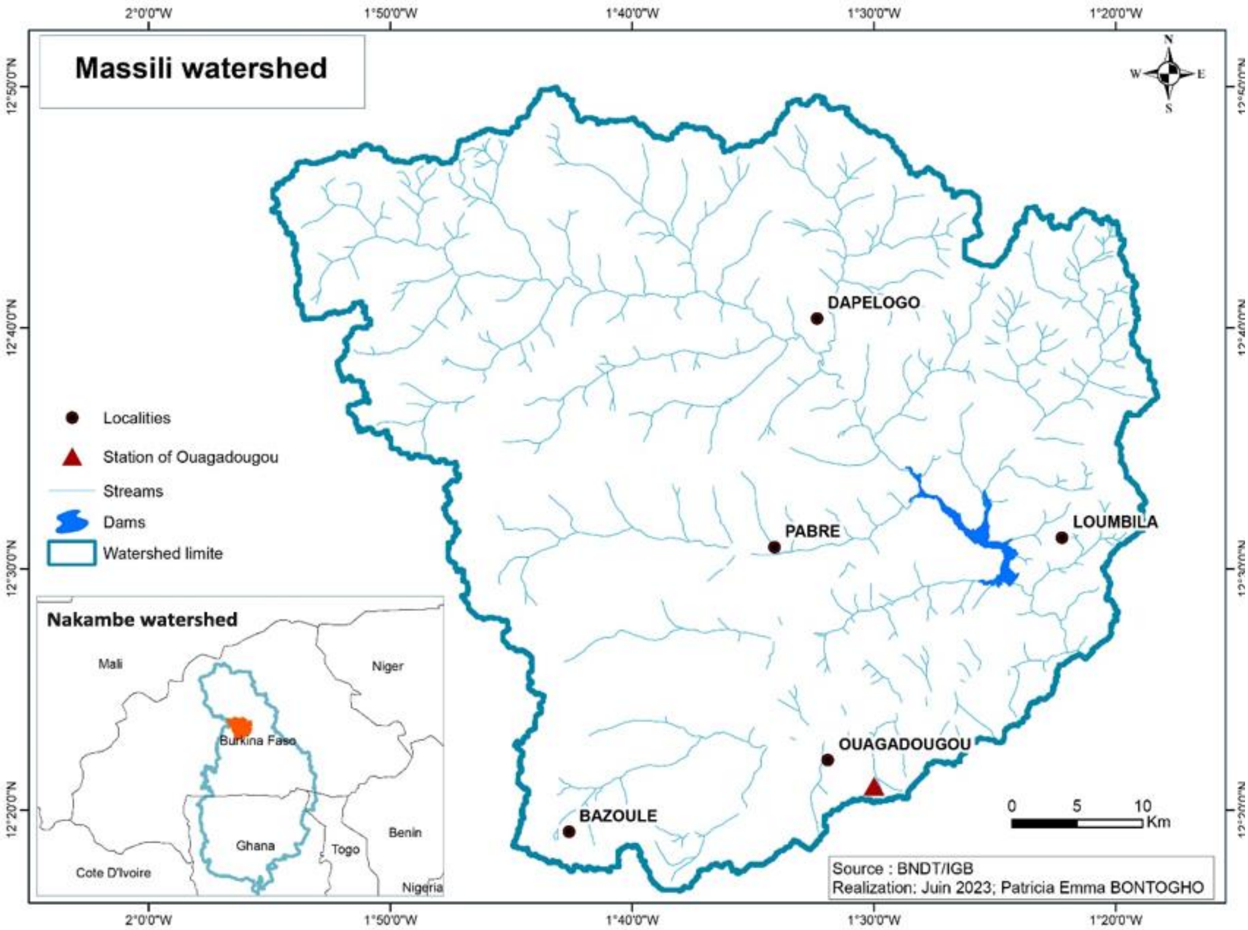

Figure 1. Massili watershed limited at Gonse station.

2.2. Climatic Datasets

In the present study, dataset of monthly maximum (Tmax) and minimum (Tmin) temperatures, and precipitation (P) covering the period 1960 to 2021, were collected from the National Meteorological Agency of Burkina Faso. As stated in Bontogho, et al. [26], the time series are considered good quality data with missing values completed using linear regression method in SPSS. Table 1 provides the statistics of the observed records for the 1960-2021 period over Massili basin. The SPEI data obtained in the previous paper is used as input in this study.

Table 1. Basic statistics of Massili rainfall and temperature.

Parameters	Prcp	Tmax.	Tmin.
Sd	84.98	2.82	3.35
Skewness	1.33	0.13	-0.25
Kurtosis	4.05	2.15	2.64
Shapiro w	0.78	0.98	0.98

2.3. Methodology

To assess the characteristics of drought within the study area, SPI was calculated. The SPI is the number of standard deviations by which the observed anomaly deviates from the long-term mean. The Standardized Precipitation index (SPI) used to evaluate climatological drought characteristics is described by the following equation:

$$\text{SPI} = \frac{(Xi - \bar{X})}{\sigma}$$

Where X_i represents the rainfall for year i, $\bar{X}$ refers to the long-term average rainfall and σ stands for the standard deviation.

Table 2 gives the SPI values based on the McKee classification system. A drought event refers to SPI values ranging from -1 to less than −2.00 while wet conditions are represented by SPI values spanning from 1 to more than 2. Globally, SPI values above zero indicates above normal precipitation and SPI values below zero refers to below normal precipitation.

Table 2. The SPI categories based.

SPI Categorization	SPI values
Extreme wet	SPI ≥ 2.00
Severe wet	1.50 ≤ SPI < 2.00
Moderate wet	1.00 ≤ SPI < 1.50
Near normal wet	−1.00 < SPI < 1.00
Moderate dry	−1.50 < SPI ≤ −1.00
Severe dry	−2.00 < SPI ≤ −1.50
Extreme dry	SPI ≤ −2.00

Note: McKee, et al. [22].

2.4. Spearman Correlation Test

Spearman correlation method has been applied to calculate the correlation for the index. According to Van Dongen and Enright [27] Spearman's rank correlation coefficient is a nonparametric rank statistic proposed as a measure of the strength of the association between two variables.

3. RESULTS AND DISCUSSION

Figure 2 illustrates the evolution of the values of SPI at different time scale over the Massili watershed during the period 1960–2021. The value of SPI3 range from -2,9627 to 2,8851; the values of SPE6 ranged from -2,4861 to 2,76871; the values of SPE12 ranged from -2,8047 to 2,5880; The value of SPI24 ranged from -2,6048 To 2,1839. Whatever the time scale considered in the estimation of the SPI, dry conditions prevailed in during the period 1980–1990, 1990–2000, 2000-2010. Severe wet conditions prevailed in years 1984, 1985,1998 and 2002.

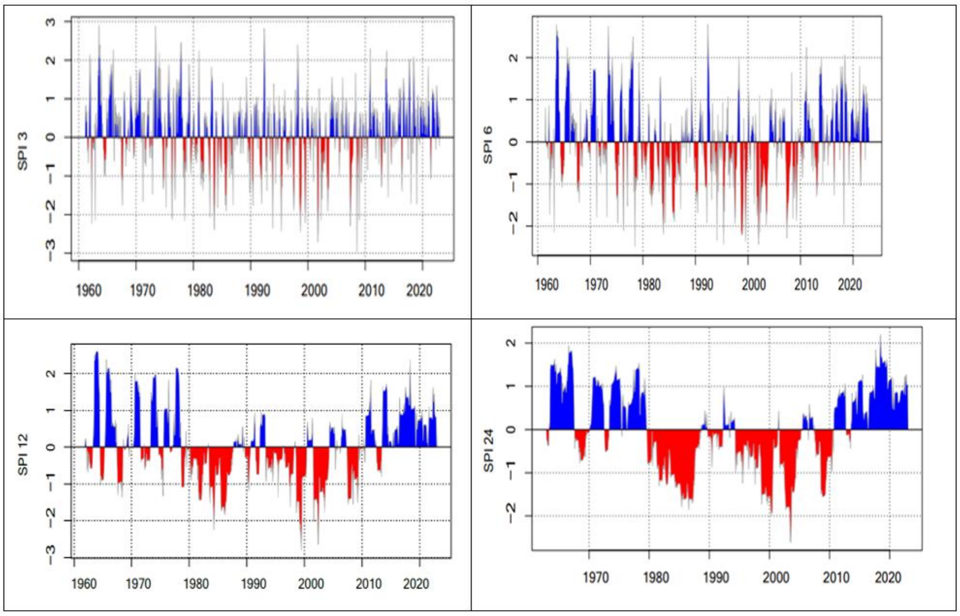

Figure 2. Massili basin SPI at different time scale accumulation from 1960 to 2021.

3.1. Characteristics of SPEI and SPI in the Massili River Basin

Figure 3 provides the boxplots for SPI3 and SPIE3. The minimum, mean, and maximum value of the SPI3 and SPEI3 over Massili watershed range from -2.9627 to -2.4819, 0.1553 to 0.0028 and 2.8852 to 2.695040 respectively. Similarly, the first quarter, median, and third quarter of SPI24 and SPEI24 vary from -0.3785 to -0.6867, 0.2556 to -0.0227 and 0.6873 to 0.7003, respectively.

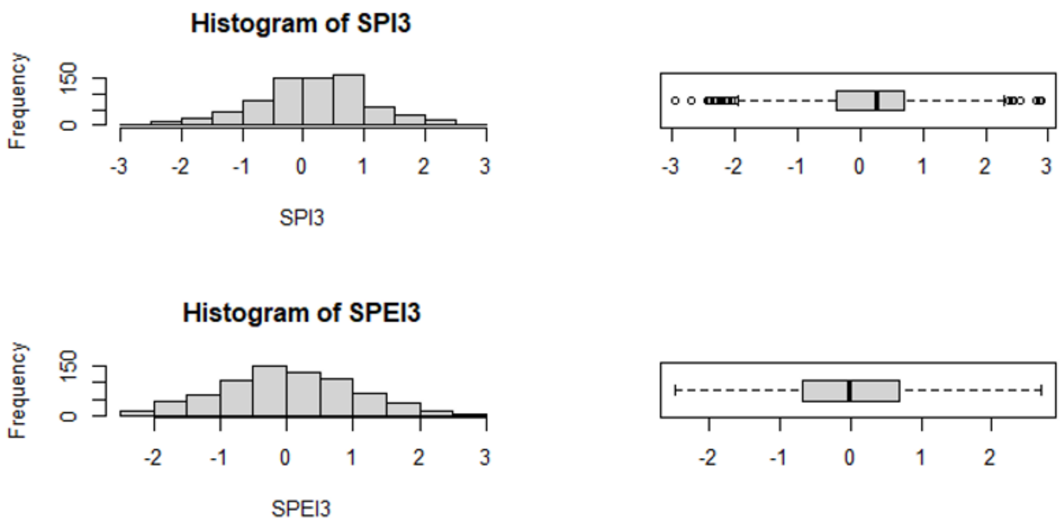

Figure 3. Boxplot of Massili basin SPEI-3 and SPI-3 from 1960 to 2021.

Figure 4 illustrates the boxplots for SPI6 and SPIE6. The boxplots for SPI6 and SPEI6 show that the minimum, mean, and maximum value of the SPI6 and SPEI6 over Massili watershed range from -2.4861 to -2.4289, 0.0018 to 0.0049 and 2.7709 to 2.6367 respectively. Similarly, the first quarter, median, and third quarter of SPI6 and SPI6 vary from -0.5990 to -0.6454, -0.0146 to -0.0497 and 0.6398 to 0.6961, respectively.

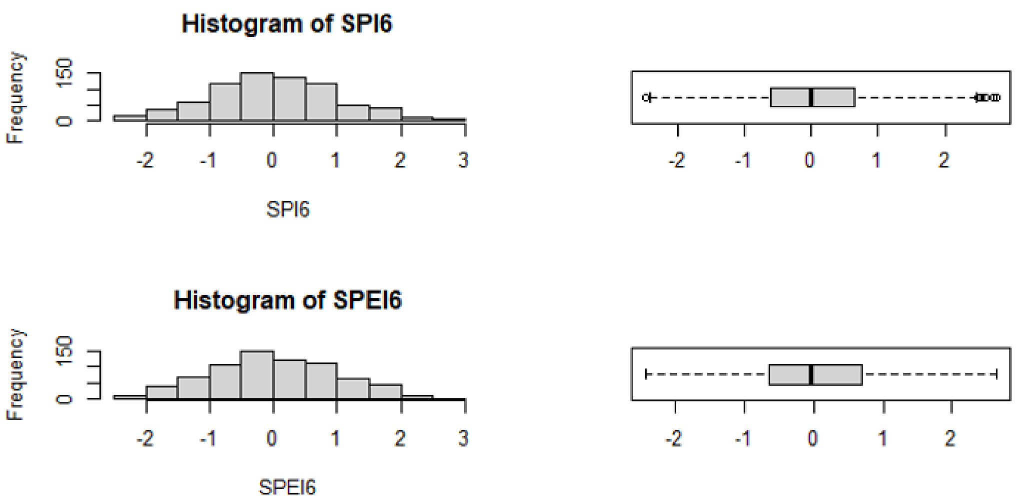

Figure 4. Boxplot of Massili basin SPEI-6 and SPI-6 at different time from 1960 to 2021.

Figure 5 provides the boxplots for SPI12 and SPIE12. The boxplots for SPI12 and SPEI12 show that the minimum, mean, and maximum value of the SPI12 and SPEI12 over Massili watershed range from-2.8047 to -2.3973, 0.0019 to 0.0061 and 2.5880 to 2.1947 respectively. Similarly, the first quarter, median, and third quarter of SPI12 and SPEI12 vary from -0.6857 to -0.7247, -0.0602 to 0.0125, and 0.6014 to 0.7328, respectively.

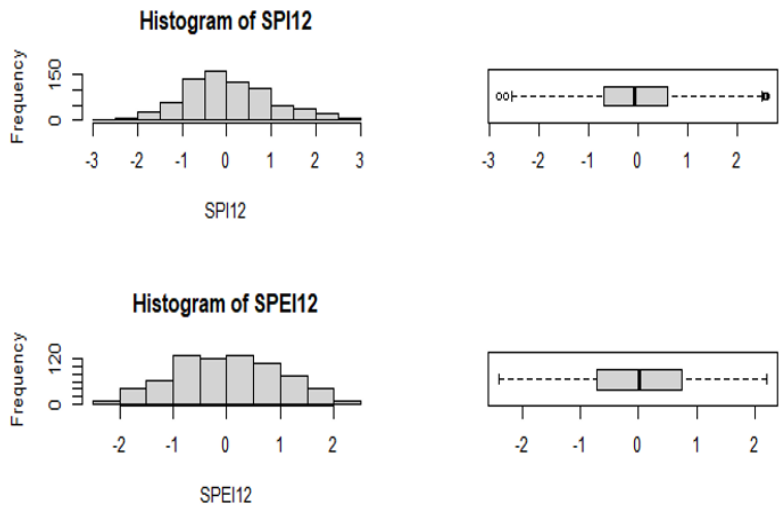

Figure 5. Boxplot of SPI12 and SPEI12 from 1960 to 2021.

Figure 6 gives the frequency and the boxplots of SPI and SPEI on the annual scale (24 months). The boxplots for SPI 24 and SPEI24 show that the minimum, mean, and maximum value of the SPI24 and SPEI24 over Massili watershed range from -2.6047 to -2.2873, 0.0026 to -0.0012, and 2.1839 to 2.1379, respectively. Similarly, the first quarter, median, and third quarter of SPEI24 and SPI24 vary from -0.6843 to -0.8064, -0.0726 to -0.0778, and 2.1839 to 2.1379, respectively.

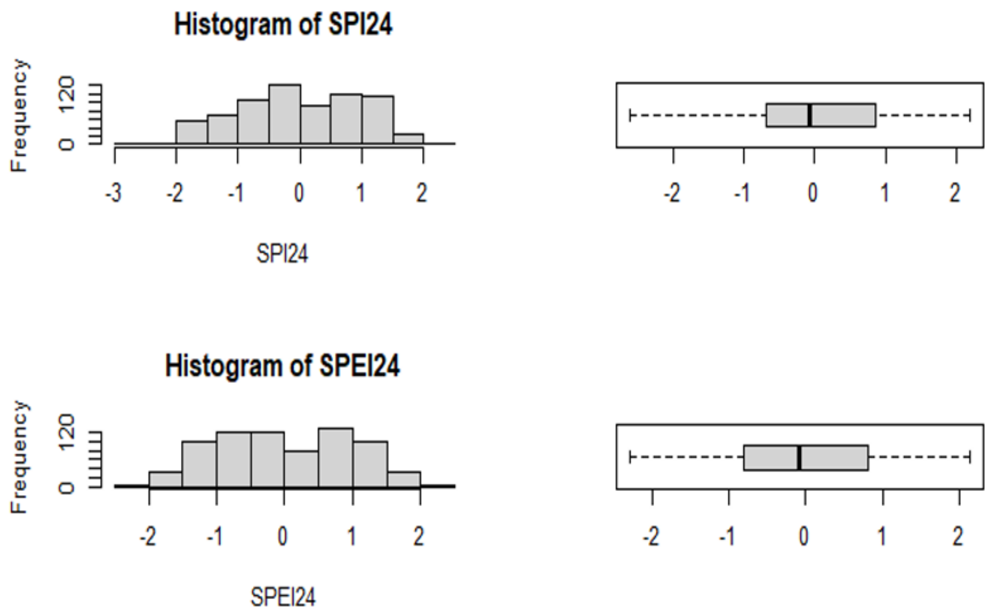

Figure 6. Boxplot of SPI24 and SPEI24 over 1960-2021.

Figure 7 provides an overview of the Spearman correlations between the SSI and the SPI at different time scales within the watershed. SPEI and SPI at various time scale are significantly correlated. SPEI3 and SPI3 exhibit a correlation value of 0.82. A value of 0.93 is observed as the correlation coefficient between SPEI6 and SP6. 0.96 is the value of the correlation coefficient identified between SPEI12 and SPI12. SPEI24 and SPI 24 however are found to have the highest correlation (0.97). Based on the classification of Spearman coefficient, it is apparent that in all time scale the SPEI and SPI are characterized by high correlation within the watershed since the Spearman correlation coefficients are very strong (above 0.7). Consequently, the SPEI and SPI at various scale have serial dependence [28].

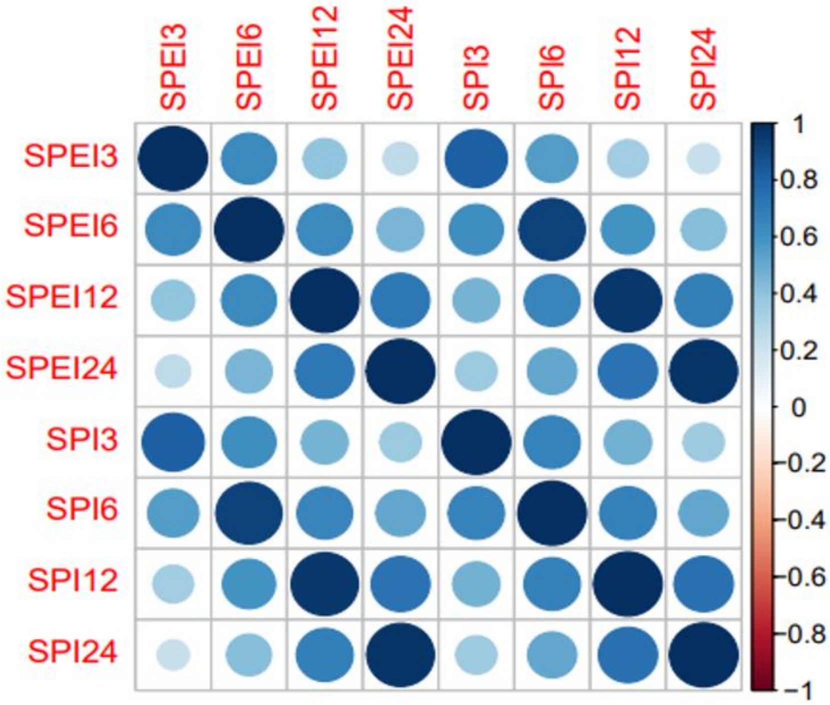

Figure 7. Correlation graph for SPEI and SPI values at various time scale in Massili Watershed.

4. CONCLUSION

In the present study, comparative analysis of meteorological drought characteristics within Massili watershed based on the Standardized Precipitation Evapotranspiration index and the Standardized Precipitation index was carried out. Despite the similarities and differences detected between the two methods, it came out from the results that both technics have the ability to reproduce the drought episodes within the basin. SPEI sound to underestimate the drought events comparatively to the SPI. Nonetheless, correlation coefficients indicate that there is a strong correlation between SPEI and SPI values across the watershed. The results of the study are also relevant for climate change studies to understand historical patterns and to develop future drought scenarios for water resources management perspectives.

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Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

REFERENCES

[1] T. Wheeler and J. Von Braun, "Climate change impacts on global food security," *Science*, vol. 341, no. 6145, pp. 508-513, 2013.

[2] M. Jahn, "Economics of extreme weather events: Terminology and regional impact models," *Weather and Climate Extremes*, vol. 10, pp. 29-39, 2015. https://doi.org/10.1016/j.wace.2015.08.005

[3] S. Alfonso, M. Gesto, and B. Sadoul, "Temperature increase and its effects on fish stress physiology in the context of global warming," *Journal of Fish Biology*, vol. 98, no. 6, pp. 1496-1508, 2021. https://doi.org/10.1111/jfb.14599

[4] J. Sheffield and E. F. Wood, "Drought: Past problems and future scenarios." London, Washington DC: Earthscan, 2011, p. 210.

[5] A. Zargar, R. Sadiq, B. Naser, and F. I. Khan, "A review of drought indices," *Environmental Reviews*, vol. 19, no. NA, pp. 333– 349, 2011.

[6] S. Song and V. P. Singh, "Meta-elliptical copulas for drought frequency analysis of periodic hydrologic data," *Stochastic Environmental Research and Risk Assessment*, vol. 24, no. 3, pp. 425-444, 2010. https://doi.org/10.1007/s00477-009-0331-1

[7] A. F. Van Loon, "Hydrological drought explained," *Wiley Interdisciplinary Reviews: Water*, vol. 2, no. 4, pp. 359-392, 2015. https://doi.org/10.1002/wat2.1085

[8] B. F. Thomas and J. S. Famiglietti, "Identifying climate-induced groundwater depletion in GRACE observations," *Scientific Reports*, vol. 9, no. 1, p. 4124, 2019. https://doi.org/10.1038/s41598-019-40155-y

[9] M. S. Rathore, "State level analysis of drought policies and impacts in Rajasthan, India," Working Paper No. 93 (Drought Series, Paper 6). Colombo, Sri Lanka: International Water Management Institute, 2005.

[10] L. C. Stringer, J. C. Dyer, M. S. Reed, A. J. Dougill, C. Twyman, and D. Mkwambisi, "Adaptations to climate change, drought and desertification: Local insights to enhance policy in southern Africa," *Environmental Science & Policy*, vol. 12, no. 7, pp. 748-765, 2009. https://doi.org/10.1016/j.envsci.2009.04.002

[11] C. Gu, X. Mu, P. Gao, G. Zhao, and W. Sun, "Changes in run-off and sediment load in the three parts of the Yellow River basin, in response to climate change and human activities," *Hydrological Processes*, vol. 33, no. 4, pp. 585-601, 2019. https://doi.org/10.1002/hyp.13345

[12] ED DAT, "The international disaster ", Retrieved: https://www.emdat.be. [Accessed 13 January 2014], 2009.

[13] H. Eswaran, R. Lal, and P. F. Reich, "Land degradation," presented at the In An Overview Conference On Land Degradation and Desertification, Khon Kaen, Thailand: Oxford, New Dehli, 2001.

[14] C. L. Bielders, A. Vrieling, J. L. Rajot, and E. Skidmore, "On-farm evaluation of field-scale soil losses by wind erosion under traditional management in the Sahel," in *In Soil Erosion Research for the 21st Century: Proceedings of the International Symposium, 3-5 January 2001, Honolulu, Hawaii, USA*, 2001, pp. 494-497.

[15] P. E. Hulme, "Herbivory, plant regeneration, and species coexistence," *Journal of Ecology*, vol. 84, no. 4, pp. 609-615, 1996. https://doi.org/10.2307/2261482

[16] United Nations Development Program (UNDP), *2001. Human development report*. New York: UNDP, 2001.

[17] A. Mehran, O. Mazdiyasni, and A. AghaKouchak, "A hybrid framework for assessing socioeconomic drought: Linking climate variability, local resilience, and demand," *Journal of Geophysical Research: Atmospheres*, vol. 120, no. 15, pp. 7520-7533, 2015. https://doi.org/10.1002/2015jd023147

[18] D. Ruelland, A. Tribotte, C. Puech, and C. Dieulin, "Comparison of methods for LUCC monitoring over 50 years from aerial photographs and satellite images in a Sahelian catchment," *International Journal of Remote Sensing*, vol. 32, no. 6, pp. 1747-1777, 2011. https://doi.org/10.1080/01431161003623433

[19] R. Kasei, B. Diekkrüger, and C. Leemhuis, "Drought frequency in the Volta basin of West Africa," *Sustainability Science*, vol. 5, no. 1, pp. 89-97, 2010. https://doi.org/10.1007/s11625-009-0101-5

[20] M. P. Van Rooy, "'A rainfall anomaly index independent of time and space," *Notos*, vol. 14, no. 43–48, 1965.

[21] H.-R. Byun and D. A. Wilhite, "Objective quantification of drought severity and duration," *Journal of Climate*, vol. 12, no. 9, pp. 2747-2756, 1999. https://doi.org/10.1175/1520-0442(1999)012%3C2747:oqodsa%3E2.0.co;2

[22] T. B. McKee, J. Nolan, and J. Kleist, "The relationship of drought frequency and duration to time scales," presented at the Preprints, Eighth Conf. on Applied Climatology, Anaheim, CA, Amer. Meteor, Soc, 1993.

[23] T. B. McKee, J. Nolan, and J. Kleist, "Drought monitoring with multiple time scales," presented at the Preprints, Ninth Conf. on Applied Climatology, Dallas, TX, Amer. Meteor. Soc, 1995.

[24] Z. Hao and A. AghaKouchak, "A nonparametric multivariate multi-index drought monitoring framework," *Journal of Hydrometeorology*, vol. 15, no. 1, pp. 89-101, 2014. https://doi.org/10.1175/jhm-d-12-0160.1

[25] S. Saadat, D. Khalili, A. A. Kamgar-Haghighi, and S. Zand-Parsa, "Investigation of spatio-temporal patterns of seasonal streamflow droughts in a semi-arid region," *Natural Hazards*, vol. 69, pp. 1697-1720, 2013. https://doi.org/10.1007/s11069-013-0783-y

[26] T.-N. P. E. Bontogho, M. M. R. Kansole, M. Kabore, and M. Guira, "Patterns of meteorological drought using standardized precipitation evapotranspiration index for Massili Basin, Burkina Faso," *International Journal of Environment and Climate Change*, vol. 12, no. 11, pp. 3368-3377, 2022. https://doi.org/10.9734/ijecc/2022/v12i111387

[27] S. Van Dongen and A. J. Enright, "Metric distances derived from cosine similarity and Pearson and Spearman correlations," *arXiv preprint arXiv:1208.3145*, 2012.

[28] F. Yusof, I. Kane, and Z. Yusop, "Hybrid of ARIMA-GARCH modeling in rainfall time series," *Technology Journal*, vol. 63, no. 2, pp. 27-34, 2013. https://doi.org/10.11113/jt.v63.1908