International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 44 No. 1 Nov. 2024, pp. 207-215

http://www.ijias.issr-journals.org/

Assessing Meteorological and Hydrological Drought over Massili Basin Based on Pedj Drought Index (PDI), Standardized Streamflow Index (SSI), the Non-stationary Standardized Precipitation Index (NSPI)

Tog-Noma Patricia Emma Bontogho[1], Aményon Akakpo[2], Olayemi Ursula Charlène Gaba[3], and Remo Kientega[4]

[1]High Institute of Sustainable Development, University of Fada N'Gourma, Fada N'Gourma, Burkina Faso

[2]Department of Agricultural and Resource Economics, University of Saskatchewan, Saskatoon, Canada

[3]National Institute of Water, University of Abomey-Calavi, Calavy, Burkina Faso

[4]Sustainability and Innovation, Development, Equity, Sustainability and Innovation, Ouagadougou, Burkina Faso

ABSTRACT: Water availability and accessibility are major challenges in arid and semi-arid regions. Addressing the knowledge gaps regarding water resources is a critical step toward resolving this issue. This study seek to investigate hydrological and meteorological drought pattern across the Massili basin in central Burkina Faso. The method was based on the estimation of Pedj Drought Index (PDI), the Non-Stationary Standardized Precipitation Index (NSPI), the Standardized Streamflow Index (SSI), and the Precipitation index (P index). Monthly data on flow discharge (1975-2021), precipitation, and mean temperature (1960-2021) were collected and analyzed. These data were used to derive the indices and identify the characteristics of past droughts over the watershed. Results indicate severe droughts occurred in 1974, 1982, 2002, and 2010, while milder droughts were observed in 1984, 1997, 2000, 2001, and 2006. These results highlight critical drought periods in the Massili basin, with significant implications for water resource management and the development of adaptation strategies in this arid region. A deeper understanding of historical droughts can help strengthen local communities' resilience to climate variability.

KEYWORDS: Drought, Standardized Streamflow index, Pedj drought index, Massili basin, P index.

1 INTRODUCTION

Drought is defined as a period of abnormally dry weather long enough to cause a serious hydrological imbalance [1]. In a study published by [2], drought is described as a prolonged period of abnormally low precipitation that results in a significant shortage of water resources. The severity of a drought is mainly determined by its duration, geographic extent, and its impact on local ecosystems, agriculture, and human populations. Many studies have highlighted West Africa's vulnerability to drought due to its climate and geographical location ([3], [4], [5]). In Niger for instance more than 15 severe droughts episodes with devastating consequences were identified between 1900 and 2015, as stated by [6]. In addition, [7] stated that drought was dominated the early 19th century across Mali due to decreased rainfall. Then, [8] reported that several multi-year droughts have occurred in the early 20th century in central Mali. Burkina Faso, a semi-arid country, has faced recurring droughts since the 1970s. As noted by [9], the country has experienced a significant decline in annual rainfall. The most severe droughts occurred in 1973-1974 and 1983-1984. Additionally, [10] identified 2011, 2012, 2014, and 2020 as years with significant rainfall deficits. Drought is a recurring and severe issue in the Massili Basin since rainfall deficits have been observed in the basin [11], [12]).This phenomenon significantly impacts the livelihoods of local communities, particularly those reliant on agriculture and pastoralism. Conventional approaches to address meteorological and hydrological droughts can be found in the literature. For instance, Percentile-based indices, such as Q95, have been widely used for streamflow drought hazard estimation.

Standardized precipitation index (SPI) recommended by the World Meteorological Organization (WMO) as stated by [13] is commonly used as a drought indices in many studies ([14], [15], [16]). Additionally, Palmer drought severity index (PDSI) introduced by [17] is widely used to identify meteorological drought worldwide ([18], [19], [20]). The Standardized reservoir storage index (SRSI) were also used by many scholars for hydrological drought detection ([21, [22], [23). The accuracy of an index for drought detection depends primarily on its ability to reproduce drought conditions in a specific region. This requires the index to be robust, tractable, transparent, sophisticated, extensible, and consider dimensionality as stated by [24], [25], [26]. The overall goal of this study is to investigate hydrological and meteorological of Massili basin. The study aims to address the following specific questions: What are the predominant drought patterns in the Massili basin? How do hydrological and meteorological drought indices vary over time in the basin? When were the most severe drought events observed in the Massili basin? What is the ability of drought indices in reproducing drought events within the Watershed? To reach this objective, four drought index were used to investigate the inter-annual characteristics of drought and humidity in Massili watershed during 1960–2021. The Pedj Drought Index (PDI) introduced by [27] employs two climatic variables (precipitation and temperature) to evaluate drought in many regions even in areas with limited meteorological stations and short data record. PDI based on precipitation and temperature is certainly used worldwide but its ability to reproduce drought in Burkina Faso is yet to be reported. Standardized streamflow index (SSI) is an hydrological drought index described as a standardized anomaly index based on aggregated discharge [28]. The non-stationary Standardized Precipitation Index (NSPI) recently developed by [29] estimated a time dependent SPI by fitting a non-stationary gamma model to observed rainfall using a Generalized Additive Model in Location, Scale and Shape (GAMLSS) where the location parameter of the distribution varied only with time.

2 MATERIAL AND METHODS

2.1 STUDY AREA AND DATA DESCRIPTION

The Massili basin is located in central Burkina Faso, covering an area of 2,612 km^2 (figure 1). The watershed is bounded by latitudes 12°17′–12°50′ north and longitudes 1°15′–1°55′ west. The Massili is situated within two reference watersheds. Nationally, the basin is a sub-basin of the Nakambe Watershed. At the international scale, Massili basin is a part of the trans-boundary Volta Basin. The Massili Basin comprises several sub-basins, with the most significant being Donse (175 km^2), Pabre (210 km^2), Kamboince (125 km^2), Ouagadougou (350 km^2), and Loumbila (2120 km^2). The Massili Basin was selected for this study due to the presence of the Loumbila Dam, a crucial water supply source for Ouagadougou, the capital of Burkina Faso. Consequently, droughts in this region can directly influence water supply, while floods can hinder urban activities.The basin experiences an average temperature of 13.9 °C and receives an average annual precipitation of 900 mm. Rainfall as well as temperature exhibit high variability on intra-seasonal to decadal timescales. Rainfall in the Massili basin follows a unimodal regime with a short rainy season and a long dry season. The topographic elevation of the area ranges from 250 to 300 meters above mean sea level. The Massili River is a major tributary of the Nakambe River, which irrigates several countries in West Africa, including Benin, Burkina Faso, Ivory Coast, Ghana, Mali, and Togo.

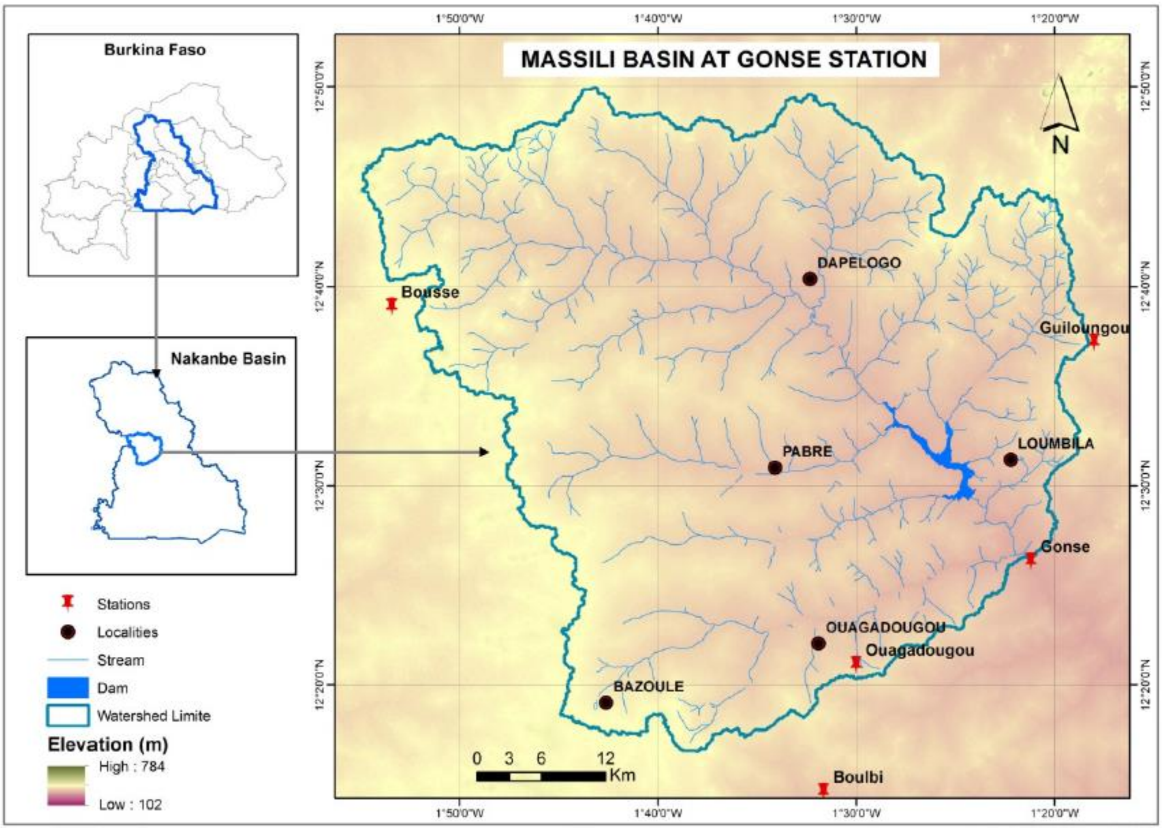

Fig. 1. Localisation of Massili basin

Source: BNDT/IGB Patricia BONTOGHO

2.2 CLMATIC DATA

This research investigates the hydrological and meteorological drought within Massili watershed. For this purpose high quality climatic dataset, including rainfall and temperature at a monthly time scale was provided by the National Agency of Meteorology of Burkina Faso. In addition, streamflow data used to estimate the hydrological drought based on SSI method were collected from the National Agency of Water Resources of Burkina Faso. The rainfall and precipitation time series are 61 years long (from 1960 to 2021) for Ouagadougou station while the streamflow records were 46 years long (from 1975 to 2021) for Gonse station. Basic statistical details for the climate dataset used in this study are presented in Table 1.

Table 1. Basic statistics of climate dataset

	Min	1st Qu	Median	Mean	3rd Qu	Max	sd
Precipitation (mm)	571.1	676.3	764.3	783.9	858.0	1183.2	138.79
Tmean (°C)	27.59	28.19	28.66	28.80	29.22	31.62	0.84
Discharge (m^3/s)	0.00	0.00	0.39	2.77	3.549	34.28	4.86

2.3 PEDJ DROUGHT INDEX (PDI)

The Pedj drought index **(PDI)** developed by [30] is used in this study to analyze the characteristics of drought in the study area. This drought index evaluates the implication of precipitation and temperature variation on drought and humidity characteristics over a given area. The PDI is expressed as:

$$PDI = SAI_{Tm} - SAI_{pr}$$

SAI_{Tm} stands for the standardized anomaly indices of mean temperature and is calculated as:

$$SAI_{Tm} = \frac{(x - \bar{x})}{s}$$

Where x is a recorded temperature of a particular year, $\bar{x}$ is the mean temperature of all the year records, and s is the standard deviation of temperature.

SAI_{pr} stands for the standardized anomaly indices of precipitation on the annual scale at the given meteorological station

$$SAI_{pr} = \frac{(x - \bar{x})}{s}$$

Where x is a recorded precipitation of a particular year, $\bar{x}$ is the mean precipitation of all the year records, and s is the standard deviation of precipitation.

Table 2. Classification of Pedj drought index

Drought	Abbreviation	PDI range
Extreme drought	D_4	More than 3
Severe drought	D_3	2-3
Moderate drought	D_2	1-2
Light drought	D_1	0-1
Normal	N	0
Light humidity	H_1	0 to -1
Moderate humidity	H_2	-2 to -1
Severe humidity	H_3	-3 to -2
Extreme humidity	H_4	Less than -3

2.4 THE NON-STATIONARY STANDARDIZED PRECIPITATION INDEX (NSPI)

In addition to the PDI, the non-stationary Standardized Precipitation Index (NSPI) has been applied in this study to evaluate the characteristics of droughts in the study area. It employs a statistical model namely Generalized Additive Model for Location, Scale and Shape (GAMLSS) approach which has been developed by [27]. GAMLSS is computed as:

$$g_k(\theta_k) = X_k\beta_k + \sum_{j=1}^{J_k} h_{jk}(\, x_{jk})$$

Where:

k = 1, 2; $\theta_1$and θ_2 are the location and scale parameters of the gamma distribution with the link functions g_1 and g_2 respectively;

X_k is a matrix of explanatory variables of order NxJ_k (J_k is the number of the covariates, and N is the length of the covariate vector); β_k (β_{1k},..., $\beta_{jk}{}^{k}$) is length of parameter vector (jk); and h_{jk} represents the function of the distribution parameters on the covariates x_{jk}. The function can be linear or smooth through smoothing terms.

The ability of the GLASSM model to fit precipitation dataset is assessed based on Global Deviance (GD), the Aikaike Indice citerion (AIC) and the Schwarz Bayesian Criterion (SBC). Akaike information criterion (AIC) is defined as a metric used to compare the goodness of fit for different regression models, were applied to retrieve different combinations of covariates. Then the best fitted GLASSM model with the low value of AIC was selected as the best combination.

The AIC is expressed as:

$$AIC = 2K - 2\ln(L)$$

Where K represents the number of model parameters and ln (L) stands for the log-likelihood of the model. This tells us how likely the model is, given the data.

2.5 STANDARDIZED STREAMFLOW INDEX (SSI)

In this study, the SSI suggested by [31] was adopted to estimate the hydrological drought condition over Massili basin. The Standardized streamflow Index (SSI) is estimated based on the aggregation of discharge data over a user-defined accumulation period (often 1, 3, 6, 12 or 24 months). Furthermore, a probability distribution function is fitted to the aggregated discharge data for each time-scale. The calculated SSI value represents the number of standard deviations away from the typical accumulated discharge and provide indication of hydrological drought severity over a given watershed. Monthly features of the SSI were then calculated and were aggregated on a yearly basis.

The monthly SSI metric is defined as the difference between a flow value and the streamflow mean divided by the streamflow standard deviation

$$SSI_i = \frac{(Q_i - \bar{Q})}{\sigma}$$

Where *Qi* is the mean discharge of month *i, Q* is the arithmetic mean of discharge, and *σ* is the standard deviation of discharge. Positive values signify higher-than-average flows, whereas negative values indicate dry periods. The drought severity classification of the SSI adopted from [32] is shown in Table 3.

Table 3. Classification of drought based on the SSI

Class	Severity
SSI ≥ 0.0	No-Drought
−1.0 ≤ SSI < 0.0	Mild Drought
−1.5 ≤ SSI < −1.0	Moderate Drought
−2.0 ≤ SSI < −1.5	Severe Drought
SSI ≤ −2.0	Extreme Drought

2.6 ESTIMATION OF P INDEX

[33] defined Percentage (P) as a drought index used to estimate the percentage of a long-term mean precipitation in the study area. According to [34] the drought occurred when the percentage of the precipitation is less than 80% of the long-term mean value. Index P is expressed as precipitation versus long- term mean precipitation multiplied by 100%.

Table 4. The drought criteria proposed for Percentage (P) indices

Indexes P	Drought categories
80-70%	Mild
70-60%	Moderate
60-50%	Severe
50%	Extreme

3 RESULTS AND DISCUSSION

3.1 PEDJ DROUGHT INDEX (PDI)

Fig. 2 shows a trend of increasing drought severity in the Massili basin between 1960 and 2021. Drought in the study area is influenced by rainfall. Indeed, drought is primarily caused by insufficient rainfall. However, the severity of drought can be influenced by the intensity and distribution of rainfall, as well as high temperatures and low humidity, which increase evaporation rates. The annual Pedj Drought Index (PDI) values have exhibited a significant upward trend over this period, with correlation coefficient of 0.58. This indicates a gradual decline in rainfall and a corresponding increase in arid conditions. Two distinct periods can be identified within this trend: a wet period from 1962 to 1976, followed by a dry period that extended from 1977 to 2020. However, a slight recovery in rainfall is observed between 2012, 2015 and 2016. Extreme humidity events were recorded in 1962 (-3.9), 1964 (-3.2), 1972 (-3.02), and 1977 (-3.74). In recent years, the drought has intensified significantly, with PDI values reaching 2.66 in 2018, 2.40 in 2019, and 2.32 in 2020. Based on the PDI classification, these values indicate a severe drought emergence was notified in recent years. Overall, the Massili basin has experienced a substantial increase in drought severity in recent years. This trend has important implications for the watershed's resource management, agriculture, and ecosystems conservation.

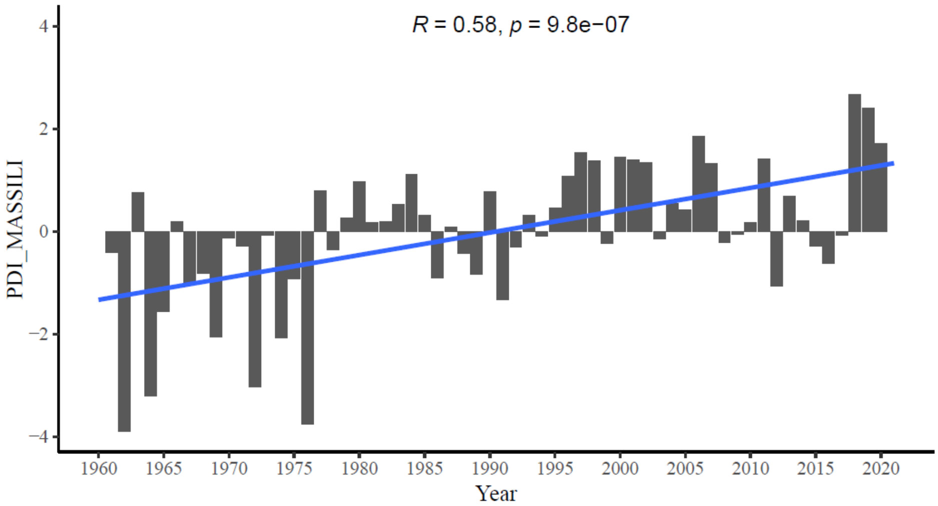

Fig. 2. PDI across Massili basin

STANDARDIZED STREAMFLOW INDEX (SSI)

Figure 3 depict the variability of the SSI over Massili basin. A general slight rising trend in the values of the standardized streamflow index in Massili river basin is observed (R=0.57) during the period 1960-2021. The highest and lowest values of SSI are 3.71 (2015) and -0.78 (1978), respectively. The higher values identified indicated that the basin has been affected by recent compound event (increase in rainfall and runoff). Excluding 2017 and 2019, the watershed has experienced continuous wet conditions from 2007 to 2021. This finding is in agreement with a study released by many scholars in the watershed ([35], [36]). This indicate that historical frequent flows have been experienced in the basin. This research aligns with the findings of [37] who reported more frequent and intense floods within the Nakambe basin. They noticed that the increased runoff can be attributed to the factors such as population growth and a significant decline in natural vegetation which, replaced by agricultural land and bare soil is make higher runoff coefficients.

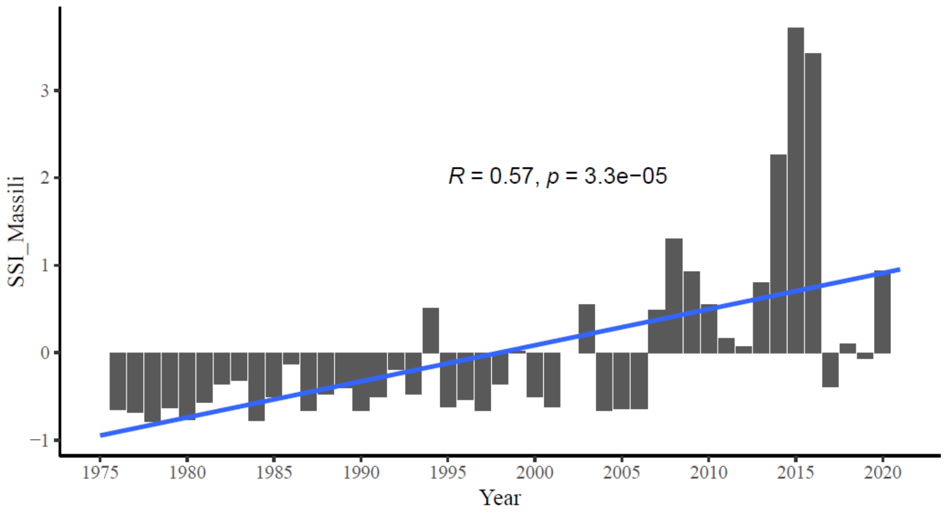

Fig. 3. Non-stationary Standardized Precipitation Index

Figure 4 provides some insight on the NSPI temporal oscillation over the Massili basin (1975-2021). Historical droughts characteristics is presented in figure 4 below. Severe droughts were identified in 1974, 1982, 2002 and 2010. However 2004 (2.1) and 2020 (2.75) are detected as the periods with large NSPI values, indicating that the basin saw more frequent high flows in recent years. Similar findings have been reported in many studies over Nakambe basin ([38], [39]). Flooding in the Massili Basin is mainly influenced by rainfall patterns, often occurring during the rainy season. However, flood is also a result of compounding factors such as urbanization and deforestation. Indeed, Ouagadougou, the capital of Burkina Faso, is located within the Massili Basin and is undergoing rapid urbanization. This urbanization leads to soil compaction, which increases runoff. Additionally, populations with limited economic resources often build informal settlements in flood-prone areas, putting them at risk during flood events. The conversion of forests into cultivated land is a significant contributor to flooding in the watershed. For instance Between 2007 and 2019, the basin experienced a substantial increase in cultivated land (8.97%). Deforestation accelerates water flow, contributing to increased flood occurrences.

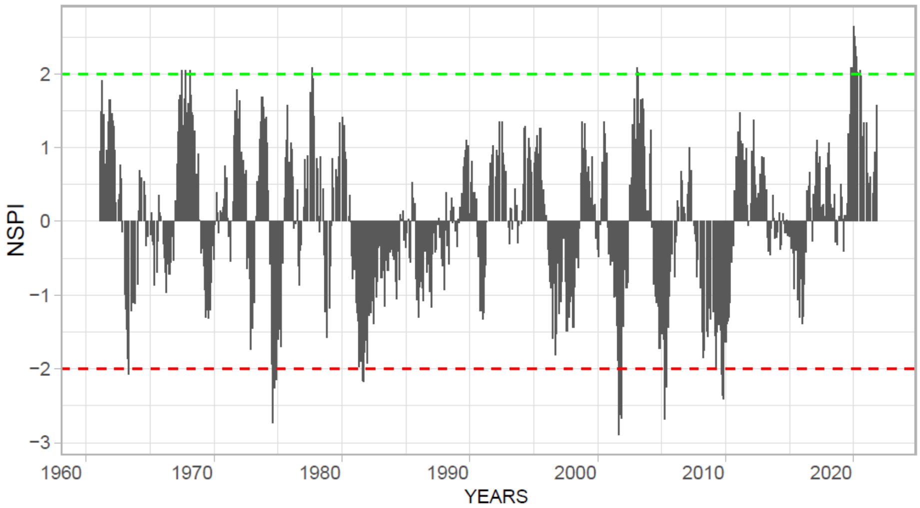

Fig. 4. NSPI variability within Massili basin from 1960 to 2021

Table 5 presents the minimum values of global deviance (GD), the Aikaike Indice criterion (AIC) and the Schwarz Bayesian Criterion (SBC) for the non-stationary model with climate indices as covariates. Among the three GAMLSS models evaluated, model 3 (GD = 3436.794) exhibited the best performance compared to model 1 (GD = 3436.847) and 2 (GS = 3436.795). Consequently, model 3 was selected as the most suitable for fitting precipitation observations and estimating the NSPI in the Massili basin.

According to [40] a drought is confirmed when the P index value is less than 80%. Using this criterion, mild droughts were identified in the Massili basin only during the years 1984, 1997, 2000, 2001, and 2006, with P values of 73%, 75%, 76%, 79%, and 76%, respectively. An analysis of the temporal oscillatory patterns in the PDI, SSI, and NSPI revealed a strong degree of consistency between the indices. All three indices exhibited similar upward and downward trends during the study period, suggesting their ability to effectively capture both meteorological (PDI, NSPI, P) and hydrological (SSI) drought conditions within the Massili basin

Table 5. GD, AIC and SBC NSPI within Massili basin from 1960 to 202

	GAMLSS-RS iteration 1	GAMLSS-RS iteration 2	GAMLSS-RS iteration 3
Global Deviance	3436.847	3436.795	3436.794
AIC	3381.61	3381.57	3381.56
SBC	3399.2	3399.2	3399.2

4 Conclusion

Understanding the watershed specific issues is essential for effective watershed management. This study evaluated flood and drought hazards in central Burkina Faso by analyzing flood and drought over the 1960-2021 period, using both meteorological and hydrological data. The PDI analysis revealed that 1962 was predominantly associated with drought events (-3.90) in the Massili basin. The highest and lowest SSI values recorded were 3.71 (in 2015) and -0.78 (in 1978), respectively. Based on NSPI analysis, severe droughts were observed in 1974, 1982, 2002 and 2010. The results identified two distinct periods: a wet period and a more recent dry period, separated by a few years of recovery. The Massili Basin is experiencing a dynamic hydrological regime, characterized by both increasing drought and flood risks. These contrasting trends highlight the need for integrated water resource management strategies that address both extremes. By understanding historical drought patterns and employing robust indices, this research contributes to the development of informed water management strategies and resilient planning in the face of climate variability. Further study will focus on the potential impacts of various climate change scenarios on flood and drought risks.

REFERENCES

[1] V. P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield, «Global Warming of 1.5°C». *In Press,* 2018.

[2] L. M. Tallaksen and H. A. J van Lanen, «Hydrological Drought Processes and Estimation Methods for Streamflow and Groundwater», *Developments in Water Science,* 48, Elsevier B.V., Amsterdam, 2004.

[3] R. Kasei, B. Diekkrüger and C. Leemhuis, «Drought frequency in the Volta basin of West Africa», *Sustainability science,* 5, 89-97, 2010.

[4] S. Adaawen, «Understanding climate change and drought perceptions, impact and responses in the rural Savannah, West Africa *». Atmosphere,* 12 (5), 594, 2021.

[5] M. Henchiri, T. Igbawua, T. Javed, Y. Bai, «Meteorological drought analysis and return periods over north and west africa and linkage with el niño–southern oscillation (Enso) ». *Remote Sensing,* 13 (23), 4730, 2021.

[6] Z. S. Abdourahamane and R. Acar, «Analysis of meteorological drought variability in Niger and its connection with climate indices». *Hydrological Sciences Journal,* 63, 2018.

[7] S. E. Nicholson, «Sub-saharan rainfall 1981–84», *Journal of climate and applied meteorology,* 24 (12), 1388-1391. (8), 1203-1218, 1985.

[8] Jacobberger, «Drought-related changes to geomorphologic processes in central Mali», *Geological Society of America Bulletin,* 100 (3), 351-361,1988.

[9] T. Lodoun, M. Sanon, A. Giannini, P.S Traoré, L. Somé and J.M. Rasolodimby, «Seasonal forecasts in the Sahel region: the use of rainfall-based predictive variables», *Theoretical and applied climatology, 117,* 485-494, 2014.

[10] A. Crawford, H. Price-Kelly, Terton, A., & Echeverría, D, «Review of current and planned adaptation action in Burkina Faso, 2016».

[11] B. Ibrahim, H. Karambiri, J. Polcher, H. Yacouba and P. Ribstein, «Changes in rainfall regime over Burkina Faso under the climate change conditions simulated by 5 regional climate models», *Climate Dynamics,* 42, 1363-1381,2014.

[12] 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», 2022.

[13] M. Svoboda, M. Hayes and D. Wood, «Standardized precipitation index», *user guide,* 2012.

[14] J. H. Stagge, L.M. Tallaksen, L. Gudmundsson, A.F. Van Loon and K. Stahl, « Candidate distributions for climatological drought indices (SPI and SPEI)», *International Journal of Climatology,* 35 (13), 4027-4040,2015.

[15] L. Li, D. She, H. Zheng, P. Lin and Z.L. Yang, «Elucidating diverse drought characteristics from two meteorological drought indices (SPI and SPEI) in China», *Journal of Hydrometeorology,* 21 (7), 1513-1530,2020.

[16] C. Faye, «Comparative analysis of meteorological drought based on the SPI and SPEI indices», *HighTech and Innovation Journal*, Vol. 3, Special Issue, 2022.

[17] W. C. Palmer, «Meteorological drought», (Vol. 30). *US Department of Commerce, Weather Bureau*.

[18] N. Wells, S. Goddard and M.J. Hayes, «A self-calibrating Palmer drought severity index», *Journal of climate, 17* (12), 2335-2351,1965; 2004.

[19] J.Mika, S.Z. Horvath, L. Makra and Z. Dunkel, «The Palmer Drought Severity Index (PDSI) as an indicator of soil moisture», *Physics and Chemistry of the Earth,* Parts A/B/C, 30 (1-3), 223-230,2005.

[20] A. Dai, «Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008», *Journal of Geophysical Research: Atmospheres,* 116 (D12), 2011.

[21] M. Gusyev, A. Hasegawa, J. Magome, D. Kuribayashi, H. Sawano and S. Lee, «Drought assessment in the Pampanga River basin, the Philippines–Part 1: Characterizing a role of dams in historical droughts with standardized indices», *In Proceedings of the 21st international congress on modelling and simulation (MODSIM 2015), November 29th–December 4th, Queensland, Australia, 2015.*

[22] Y. Wang, T. Peng, Q. Lin, V. P. Singh, X. Dong, C and G Wang, «A new non-stationary hydrological drought index encompassing climate indices and modified reservoir index as covariates», *Water Resources Management,* 36 (7), 2433-2454,2022.

[23] J. Zhou, X. Chen, C. Xu and P. Wu, «Assessing socioeconomic drought based on a standardized supply and demand water Index», *Water Resources Management,* 36 (6), 1937-1953,2022.

[24] A. Frank, T. Armenski, M. Gocic, S. Popov and S. Trajkovic, «Influence of mathematical and physical background of drought indices on their complementarity and drought recognition ability», *Atmospheric research,* 194, 268-280,2017.

[25] P. S Wable, M.K Jha and A. Shekhar, « Comparison of drought indices in a semi-arid river basin of India», *Water resources management,* 33, 75-102,2019.

[26] A. R Zarei, M. Mokarram and M.R. Mahmoudi, «Comparison of the capability of the Meteorological and Remote Sensing Drought Indices», *Water Resources Management,* 37 (2), 769-796,2023.

[27] D. A. Pedj, «On the indicator of drought and moisture surplus», In Proceedings of HMC of USSR (Vol. 156, pp. 19-38), Beijing, China: Science Press, 1975.

[28] Y. Pan, Y. Zhu, H. Lü, A.L. Yagci and R. Liu, «Accuracy of agricultural drought indices and analysis of agricultural drought characteristics in China between 2000 and 2019», *Agricultural Water Management,* 283, 108305,2023.

[29] S.A Muter, Y. Al-Timimi and M.H Al-Jiboori, «Analysis of Temporal and Spatial Drought Characteristics in Iraq Using the Standard Precipitation Index (SPI)», *IOP Conference Series: Earth and Environmental Science* (Vol. 1371, No. 2, p. 022032). IOP Publishing, 2024.

[30] Y. Wang, T. Peng, Q. Lin. V.P. Singh, X. Dong, C. Chen and G. Wang, « A new non-stationary hydrological drought index encompassing climate indices and modified reservoir index as covariates», *Water Resources Management,* 36 (7), 2433-2454,2022.

[31] D.A. Pedj, «On the indicator of drought and moisture surplus», In Proceedings of HMC of USSR (Vol. 156, pp. 19-38). *Beijing, China: Science Press,* 1975.

[32] L. Telesca, M. Lovallo, I. Lopez-Moreno and S. Vicente-Serrano, «Investigation of scaling properties in monthly streamflow and Standardized Streamflow Index (SSI) time series in the Ebro basin (Spain)», *Physica A: Statistical Mechanics and its Applications,* 391 (4), 1662-1678,2012.

[33] W.M.O. World Meteorological Organization, «Drought and agriculture», *WMO Note 138 Publ WMO-392,* WMO, Geneva, 127 pp., 1975.

[34] V. Potop and J. Soukup, «Spatiotemporal characteristics of dryness and drought in the Republic of Moldova», *Theoretical and Applied Climatology,* 96, 305-318,2009.

[35] M. Idrissou, B. Diekkrüger, B.Tischbein and B. Ibrahim, «Modeling the impact of climate and land use/land cover change on water availability in an inland valley catchment in Burkina Faso», *Hydrology,* 9 (1), 12,2022.

[36] O. Amogu, L. Descroix, K. S. Yéro, E. Le Breton, I. Mamadou, A. Ali and P. Belleudy, «Increasing river flows in the Sahel», *Water,* 2 (2), 170-199,2010.

[37] W. V.M. Yameogo, Y.L. Akpa, J.H. Danumah, F. Traore, F, B. Tankoano, Z. Sanon and M. Hien, «Spatio-Temporal Evolution of Rainfall over the Period 1981–2020 and Management of Surface Water Resources in the Nakanbe–Wayen Watershed in Burkina Faso», *Earth,* 4 (3), 606-625,2023.

[38] G. Mahe, P. Diello, J.E. Paturel, B. Barbier, H. Karambiri, A. Dezetter and N. Rouche, «Decrease of rainfall and increase of runoff in the Sahel: Climatic and anthropogenic impacts on runoff of the Nakambe River in Burkina Faso», *Science et changements planétaires/Sécheresse,* 21 (4), 330-332,2010.

[39] W. V.M. Yameogo, Y.L. Akpa, J.H. Danumah, F. Traore, F, B. Tankoano, Z. Sanon and M. Hien, « Spatio-Temporal Evolution of Rainfall over the Period 1981–2020 and Management of Surface Water Resources in the Nakanbe–Wayen Watershed in Burkina Faso», *Earth,* 4 (3), 606-625,2023.

[40] V. Potop and J. Soukup, « Spatiotemporal characteristics of dryness and drought in the Republic of Moldova», *Theoretical and Applied Climatology,* 96, 305-318,2009.