Rainfall Anomaly Index over Mouhoun Basin in Southwestern Burkina Faso

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Received:- 01 June 2023/ Revised:- 08 June 2023/ Accepted:- 13 June 2023/ Published: 30-06-2023

Abstract— *In recent decades, climate index has become an important tool in hydrological studies. Accordingly, the implication of climate change in hydrological researches requires the assessment of historical and future climate characteristics to understand current and future processes for water resources management improvement. The aim of this study is to analyze historical rainfall anomalies over the Mouhoun watershed by applying precintcon package in R studio. Required data for the assessment of the rainfall anomalies was retrieved from the National Meteorological Agency (NMA) of Burkina Faso. Purposely, monthly rainfall data of three meteorological stations spanning from 1980 to 2012 were collected. The findings revealed that within Mouhoun watershed, the rainfall data are leptokurtic and the distribution is narrower than normal. This result shows thus a moderate dry rainfall anomaly. During the second period of analysis (1990-1994), The station of Bobo Dioulasso is showing an estimated value of -2.594. This value of the RAI is indicating a slightly dry pattern of rainfall in this station. However, the stations of Boromo, is presenting a value of RAI in the range of -1. 00 to -1.99 highlighting a moderate dry rainfall characteristic. During the period (1995-1999), slightly dry conditions are detected in Bobo and Boromo. From 2000 to 2004 and 2005 to 2011, moderate dry RAI index is identified for all station except for the station of Gaoua. Among these six stations of the watershed, Gaoua station which is located in the southwestern part of the watershed has experienced throughout the period of analysis a dryness conditions. Indeed, a slightly dry rainfall anomaly is detected with a RAI ranging from -0.50 to -0.99. The results obtained could serve as a guide to decision makers in water and climatic management.*

***Keywords*— Rainfall, variability, climatic change, meteorological drought.**

I. INTRODUCTION

Rainfall as one of the main components of the hydrological cycle (Shiklomanov et al. 2000; Schneider et al.; 2010; Li et al.,2022b) is undergoing changes worldwide. Indeed, global warming is substantially leading to potential change in rainfall occurrence all over the world. As reported by IPCC (2022), an increase of temperature up to degree, may results in huge rainfall variability. Consequently, climate change, is greatly affecting the patterns of rainfall. The Sahel region, highly exposed to climate change, is gradually becoming hotter, with some areas experiencing increased and erratic rainfall. Historical records and climate projections show that the magnitude and frequency of precipitation extremes are increasing in Sahelian areas considering global, regional, and local scales. According to Nicholson et al, (2018) significant rainfall fluctuations has been registered in the Sahel. Indeed, over the last few decades, rainfall in this region has experienced profound changes such as drought and flood. Moreover, Martin et al (2016) revealed that high variabilities sound to occur in the next coming decades leading to an inappropriate water resources management. Consequently, analyzing rainfall records stand to be an important step in water resources management (Kim et al 2012; Dastorani, 2016; Borah et al; 2021). Several studies have investigated temporal and spatial changes in rainfall within Burkina Faso. Various rainfall-based indices were used to investigate the rainfall variability conditions in Burkina Faso. Using Standardized Anomaly Index (SAI), Kima et al (2015) found an upward trend, with high inter-annual variability in the Boulgou' province of Burkina Faso. While, Sagnan et al (2021) applied a standardized precipitation index to analyze the water balance in Burkina Faso. They found a slight increase in rainfall over the country in the 1990s. Over the recent years, Rainfall anomaly index analysis has become more popular in recent years (Costat 2017, Raziei 2021). Hänsel et al. (2016) applied the Modified Rainfall Anomaly Index (mRAI) in evaluating its suitability as an alternative to the Standardized Precipitation Index (SPI) in assessing future precipitation conditions. Applying Standardized precipitation evapotranspiration index (SPEI) and standardized precipitation index (SPI) to classify the precipitation and water balance anomalies in four deleted Sub-Saharan Countries (Senegal, Burkina Faso, Tanzania, and Malawi.), Mbaye et al. 2022 found high rainfall variability of extreme events in all the four countries. In a recent study, Aryal et al. (2022) applied the RAI to characterize the droughts in Népal and to evaluate their impacts on crop yields. Although rainfall analyses in Mouhoun watershed have been done by many methods such as SPI and, rainfall anomaly index analysis within the basin is still lacking. However, a number of studies have shown a comparable performance of RAI to the SPI (Keyantash and Dracup 2002; Loukas et al. 2003). According to Keyantash and Dracup (2002), the RAI offers a higher degree of transparency and tractability and demands a lower degree of sophistication than the SPI with regard to the evaluation criteria for drought indices. Analyzing the comparative performance of three meteorological drought indices, Oladipo (1985) found that differences between the RAI and the more complicated indices were negligible. Moreover, the results of the analysis suggest that precipitation is the most important climatic element as an input into meteorological drought. Therefore, the present study estimates the value of RAI within the Mouhoun watershed in order to provide robust evidence on historical rainfall characteristics for decision making.

II. RESEARCH METHODOLOGY

2.1 Description of the study area

The Mouhoun River basin is located in western Burkina Faso and spans from 5°-2° W to 9°-14° North. The watershed covers an area of 91 036 km² that account of 22.32% of the Volta River basin. This transboundary River extends on 1000 km in Burkina Faso and is divided into three national sub-basins: the upper Mouhoun (20 978 km^2) and the Lower Mouhoun (54 802 km^2) and the Sourou (15 225 km^2). The upper Mouhoun has perennial flows in its upstream part with low water levels that are rarely less than 2 m^3/s both at the Samandéni station and on the Kou at Nasso. The Upper Mouhoun limited to the confluence of the Sourou is mainly drained by five main tributaries which are the Plandi, the Kou, the Voun Hou. In general, during floods the Mouhoun drains its tributaries but during recession, a reverse situation is observed since it is the Sourou that drains the Mouhoun. The lower Mouhoun abruptly changes direction after the loop of the Sourou, it flows towards the south-east, then due south, forming the border with Ghana from Ouessa. The part of the Mouhoun river under study crosses the Sudano-Guinean and Sudanese climatic zones, with average annual rainfall between 750 and 1050 mm. The relief of the basin is quite monotonous with an average slope of 2%. The altitudes are between 273 m and 733 m (Tiemtore, 2017) The vegetation cover of the basin is essentially made up of wooded savannas, open forests and forest galleries along the permanent watercourses, whose width increases as one goes southward. Due to its geographical location, the study area enjoys a Sudanese type climate with an average annual rainfall of over 900 mm. Over the last fifty years, there has been a decline in annual rainfall in the 1970s and 1980s and an increasing trend over the last two decades (figure 6)

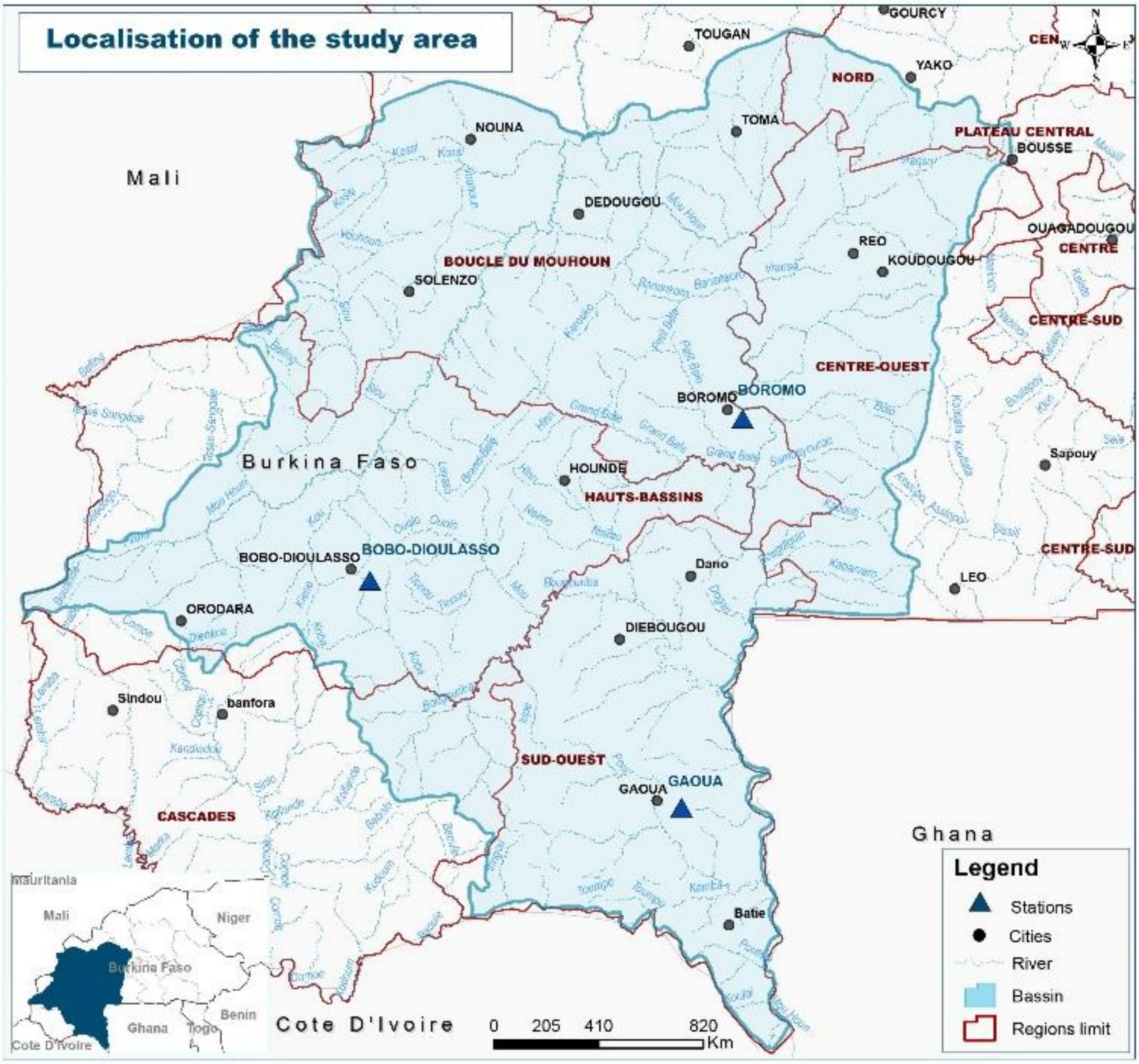

FIGURE 1: Localization of the study area

2.2 Data

Monthly rainfall data from 1980 to 2012 were provided by the National Meteorological Service (DGM) of Burkina Faso. Three rainfall stations, spread across, the Mouhoun catchment were selected (Fig. 1). Missing value were completed using regression method.

2.3 Assessment of Normality

To test the normality of the dataset, the skewness and the kurtosis of the data was estimated. Then, the Shapiro test was performed for all stations. As stated by Kim et al (2013), Skewness is a measure of the asymmetry of a variable and kurtosis is a measure of 'peakedness' of a distribution. The skew value of a normal distribution is zero, usually implying symmetric distribution. According to West et al. (1996) a positive skew value indicates that the tail on the right side of the distribution is longer than the left side and the bulk of the values lie to the left of the mean. Controversially, a negative skew value indicates that the tail on the left side of the distribution is longer than the right side and the bulk of the values lie to the right of the mean.

The following equation shows the formula of the skewness. The test is based on the density function, which is divided into slices through class intervals. The smaller the value of the chi-squared statistic, the better the expected fit of the model to the sample at hand, which is computed by:

$$\boldsymbol{S_k} = \frac{\frac{\sum_{i=1}^{N}(k_i-\bar{k})^3}{N}}{\sigma_{\bar{k}}^{3}} \tag{1}$$

Similarly, the Kutosis test allow to detect the normality of the data set. The Kurtosis is defined as the ratio of the mean square successive difference between the years to the variance. The test statistic is given as follow:

$$\boldsymbol{K_u} = \frac{\frac{\sum_{i=1}^{N}(k_i-\bar{k})^4}{N}}{\sigma_{\bar{k}}^{4}} \tag{2}$$

The Shapiro-Wilk test which was introduced by Shapiro et al (1965) is a normality test designed to detect all departures from normality. The estimations for this test are based on the algorithm developped by Royston (1995). Indeed, the Shapiro-Wilk test relies on a correlation of sample "order statistics" with statistics of a normal distribution. The Shapiro-Wilk test statistic W is defined as:

$$W = \frac{\left(\sum_{i=1}^{n} a_i X_{(i)}\right)^2}{\left(\sum_{i=1}^{n}(X_{(i)}-\bar{X}\right)^2} \tag{3}$$

Where $X_{(1)} \leq X_{(2)} \leq \ldots\ldots \leq X_{(n)}$ are the ordered values of the sample and a_i are tabulated constants. Normality is rejected for small values of W.

2.4 Estimation of the Rainfall Anomaly Index (RAI)

The rainfall anomaly index (RAI), designed by van Rooy in 1965, is used to identify positive and negative precipitation anomalies over a historical series. According to Rooy (1965), the RAI aims to make the comparison between precipitation deviations in different regions feasible. The first step in applying RAI is to rank in descending order of magnitude the precipitation values for the period of study. Then, the mean of the ten highest precipitation values and the mean of the ten lowest precipitation values for the period of study are estimated. The positive and negative RAI indices are computed by using the mean of ten extremes.

The RAI is expressed as follows:

$$RAI = 3\left[\frac{N-\bar{N}}{\bar{M}-\bar{N}}\right] \text{ for the positive anomaly} \tag{4}$$

$$RAI = -3\left[\frac{N-\bar{N}}{\bar{X}-\bar{N}}\right] \text{ for the negative anomaly} \tag{5}$$

where N is the current monthly/seasonal/annual precipitation;

$\bar{N}$ stands for the average monthly precipitation of the dataset

$\bar{M}$ represents the average of ten highest monthly precipitations record

$\bar{X}$ is the average of ten lowest monthly precipitations record;

N – $\bar{N}$ refers to the positive anomaly and negative anomaly based on positive or negative values.

The classification of the index used by Rooy (1965) is as follows.

TABLE 1
THE CLASSIFICATION OF THE INDEX USED BY ROOY (1965)

S /n	RAI	Class Description	S /n	RAI	Class Description
1	**≥3.00**	**Extremely wet**	6	**-0.50 to -0.99**	**Slightly dry**
2	**2.00 to 2.99**	**Very wet**	7	**-1.00 to -1.99**	**Moderate dry**
3	**1.00 to 1.99**	**Moderate wet**	8	**-2.00 to -2.99**	**Very dry**
4	**0.50 to 0.99**	**Slightly wet**	9	**≤-3.00**	**Extremely dry**
5	**0.49 to -0.49**	**Near Normal**			

III. RESULTS AND DISCUSSION

3.1 Normality assessment

The Normality test results presented in Table 2 indicate that the rainfall records are significantly skewed to the right (Skewness = 1.264701, 1.396572, and 1.277155 respectively in Bobo Dioulasso, Boromo and Gaoua stations). As stated in Hennessy (2009), a normal distribution exhibits zero skewness, while negative values indicate that the distribution has a heavy left tail and positive values indicate that the distribution has a heavy right tail. Based on the results obtained from the three stations, it can be concluded that across Mouhoun watershed, the rainfall distribution has a heavy right. In addition, table 1 also presents estimates kurtosis for each station. There are three categories of kurtosis that a set of data can display. When kurtosis is equal to 3, the distribution is mesokurtic; a kurtosis of less than 3 indicates that the distribution is broader than normal and is termed platykurtic; while a kurtosis of greater than 3 is characterized as leptokurtic and the distribution is narrower than normal. The results show that in all station the value of the Kurtosis is greater than 3 meaning that the data are leptokurtic and the distribution is narrower than normal. As far as the Shapiro test is concerned, the test rejects the hypothesis of normality when the p-value is less than or equal to 0.05. In all stations, the p-value of the Shapiro test turns out to be less than 0.05. Consequently, the sample data comes from a population that is normally distributed. Then, the null hypothesis that the data are normally distributed is rejected.

TABLE 2
NORMALITY TEST OF THE DATA SET

Station	*Skewness*	*Kurtosis*	*Shapiro test*	
			W	p-value
BOBO	1.264701	3.929249	0.82233	3.647e-16
BOROMO	1.396572	4.681616	0.80562	2.2e-16
GAOUA	1.277155	5.493497	0.86978	6.678e-14

3.2 Identification of rainfall anomaly in the Mouhoun watershed

Based on the classification of the RAI (Table 1), all the stations are presenting a negative value of RAI (Table 3). From 1985 to 1989, a value of -1,13 is registered at Bobo Dioulasso station, -1,17 is identified at Boromo station while the station of Gaoua is indicating -0,82 as the value of the RAI. This result shows thus a moderate dry rainfall anomaly. During the second period of analysis (1990-1994), the stations are showing an estimated values of -0,95 and -0,88, respectively in Bobo Dioulasso and Gaoua. These values of the RAI are spanning from -0.50 to -0.99 indicating a slightly dry pattern of rainfall. However, the station of Boromo is presenting a value of RAI in the range of -1.00 to -1.99 highlighting a moderate dry rainfall characteristic. During the period (1995-1999), slightly dry conditions are detected in Bobo, Boromo and Gaoua. From 2000 to 2004 and 2005 to 2011, moderate dry RAI index is identified for all station except for the station of Gaoua which is showing a slightly dry condition with a value of RAI being -0,75. Among these six stations of the watershed, Gaoua station which is located in the southwestern part of the watershed has experienced throughout the period of analysis a dryness conditions. Regardless of the time period, the overall results indicate slightly to moderate dry rainfall anomaly and this situation may lead to drought, severe shortages, low productivity, migration. Regarding the high important role given to water resource, the availability of this resources during different parts of the year are of key importance for an agricultural country like Burkina Faso specifically (Yabre et al., 2023). Indeed, the Mouhoun basin is the most fertile area of Burkina Faso and is considered as the granary of the country (Gray, 1999; McCorkle, 2019; Ouedraogo, 2022). In addition, as stated by Vlavonou et al (2020), the Boucle du Mouhoun, Center-West and South-West regions are predominantly agricultural and nearly 50% of their GDP is generated by the agricultural sector. However, high variability of rainfall affects crops production potentialities. Therefore, the assessment of the Rainfall Anomaly index in a region are that significant for reducing its vulnerability to the negative impacts of drought.

TABLE 3
VALUES OF THE RAINFALL ANOMALY INDEX WITHIN MOUHOUN WATERSHED

	1985-1989	1990-1994	1995-1999	2000-2004	2005-2011	MEAN
BOBO DIOULASSO	-1,13	-0,95	-0,86	-1,03	-1,13	-0,9925
BOROMO	-1,17	-1,13	-0,95	-1,20	-1,07	-1,0875
GAOUA	-0,82	-0,88	-0,65	-0,72	-0,75	-0,75

IV. CONCLUSION

In this paper, the Rainfall Anomaly index was performed on rainfall data recorded within Mouhoun watershed during 1985–2011. It comes out this study that drought characteristics within Mouhoun watershed is not significant. Indeed, moderate to slightly dry rainfall anomaly is identified across the basin. A slightly dry trend is observed in Bobo Dioulasso and Gaoua during the period of analysis while the station of Boromo showed a moderate trend. The findings may provide some basic rainfall characteristic for other scholars in this basin. In addition, this may help in water resources planning for decision making.

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