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Pluviometric variability of the Mouhoun basin in Burkina Faso from 1980 to 2020

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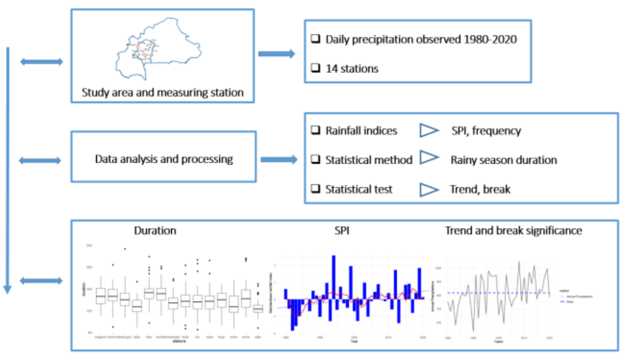
Graphical abstract



Abstract

The study aims at determination of the rainy season period and an analysis of rainfall variability in the upstream lower Mouhoun, a sub-catchment of the Mouhoun River in Burkina Faso during the period 1980-2020. Daily rainfall data from fourteen stations covering the period 1980-2020 were collected and analyzed as part of this study. The duration of the rainy season was determined using a statistical approach. Mann Kendall and Pettitt tests are used to assess the significance of trends and breaks in annual rainfall. Determination of the standardized rainfall index was used to determine the evolution of seasonality. An analysis of the return of several rainfall indices was carried out to determine the most significant ones for the majority of stations. Analysis of annual rainfall trends over the period revealed alternating wet and dry phases, with a general upward trend in cumulative annual rainfall between 1980 and 2020 during the wet season. Annual rainfall rose by 10 to 12.35 % after the breaks year at most stations. At the stations of Boromo, Didyr, Imasgo, Tiogo, and Toma, the identified break years are 1992, 2001, 2002, 1990 and 1993, respectively. The return of the wet season is more pronounced between 1990 and 2000. The length of the rainy season is decreasing at most stations, despite an increase in the number of rainy days. There has been an increase in the frequency of high-intensity rain (over 50 mm/day) and low-intensity rain (under 5 mm/day). This upsurge in high-intensity rainfall is conducive to flooding and has a negative impact on farmers' speculative crops in the basin.

Keywords: Climate change, water resources, Lower Mouhoun upstream basin, rainy season, agricultural speculations.

1. Introduction

West Africa experienced a wet period between 1950 and 1970, followed by a long rainfall deficit from 1970 to 1990. Since the mid-1990s, rainfall has picked up again (Lebel & Ali, 2009; Ozer *et al.* 2009; Salack *et al.* 2011) and recent annual averages are approaching the long-term average (1900-2015), although they differ from those of the 1950s to 1970s (Descroix *et al.* 2015; Mahé, 2006). The transition from an abnormally wet period (1950-1970) to a dry period (1970-1990) and then to a new wet period (mid-1990 to present) has led to changes in rainfall frequencies and intensities in West Africa. The dry period (1970-1990) was characterized by a notable decrease in the frequency of rainy days, while their intensity remained almost unchanged (Le Barbé *et al.* 2002; Panthou, 2013). The upturn in precipitation since the 1990s has been accompanied by an intensification of extreme events (De Longueville *et al.* 2016; Descroix *et al.* 2018; Giannini *et al.* 2013; Panthou, 2013; Panthou *et al.* 2014, 2018). This situation is detrimental to the agricultural and livestock sectors.

In Burkina Faso, the economy is essentially based on agropastoral activities, although there has been a resurgence in mining (INSD, 2022b). However, the major concern in meeting water needs for agriculture is the reliability of rainfall (Kasei *et al.* 2010; Oguntunde *et al.* 2006). Agricultural production techniques are influenced by this rainfall variability (Mahmood *et al.* 2019). However, an increase in heavy rainfall can have disastrous consequences for agricultural production. Studies of climate variability in the north-central part of the country have identified three rainy periods with declining annual rainfall totals (Kabore *et al.* 2017). There has been a decline in rainfall frequency and an increase in rainfall intensity throughout Burkina Faso (Ibrahim *et al.* 2012). The start date of the rainy season is decisive for the sowing period in food production, while the end date determines the period when crops can reach maturity (Ati *et al.* 2002; Sivakumar, 1992). This period is decisive for agricultural activities. Agriculture is practised intensively during the rainy season in Burkina Faso.

The aim of our study is to contribute to a better understanding of rainfall variability in the study area. It consists in determining the duration of the rainy season, changes in the rainfall regime and the return of rainfall for some rainfall indices over the period 1980 to 2020. Mann Kendall and Pettitt statistical tests were used to assess trends and breaks in the analysis of changes in annual rainfall.

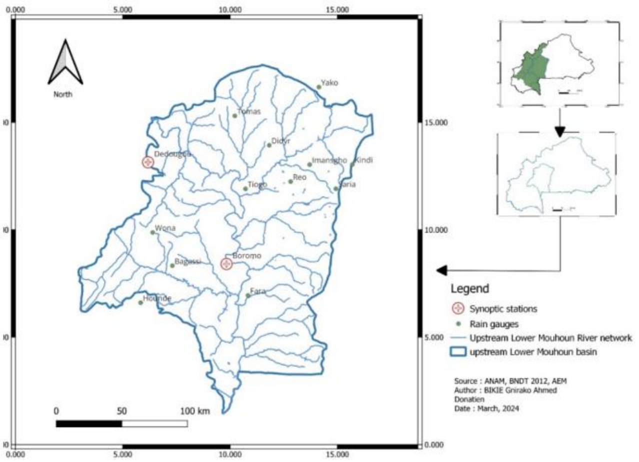


Figure 1: Lower Mouhoun Basin upstream

2. Materials and methods

2.1. Study area

Our study area (**Figure 1**) is a sub-basin of the Mouhoun river. With a surface area of 31,939 km², it cuts across six (06) administrative regions of Burkina Faso. It is located in the Sudano-Sahelian zone of the country. In this area, according to the National Meteorological Agency, annual rainfall ranges from 600 to 900 mm, with an average rainfall duration of 4 to 5 months based on the 1981-2010 average. The geographical position of the Mouhoun sub-basin and the presence of the Abidjan-Ouagadougou railroad make it the "granary of Faso" and a hub of inter-regional trade in agricultural products for Burkina Faso and sub-regional trade with neighboring countries (INSD, 2022b). Agriculture is the main activity engaging a large part of the active population. It is rudimentary and intended for subsistence, processing, and commercialization. Rain-fed crops are the most important, and the main cereal crops are maize, rice, sorghum, and millet. The main cash crops are cotton, groundnuts, voandzou, sesame, cowpea, and banana (OUEDRAOGO *et al.* 2024).

2.2. Data and methodology

2.2.1. Data

Climatic data were supplied by the National Meteorological Agency (ANAM). The data consists mainly of daily rainfall from two synoptic stations and twelve rainfall stations. Some rainfall stations do not cover the entire 1980-2020 period, with missing values (**Figure 2**). These were filled in by averaging rainfall data from neighboring stations. Our study area is primarily located in the Sudanese-Sahelian zone. It was determined based on the migration of isohyets according to the 1981-2010 normal provided by the ANAM, which presents the different climatic zones of Burkina Faso. The Mouhoun Upper Basin is located within a single climatic zone throughout our study period, and this method was used to fill the gaps.

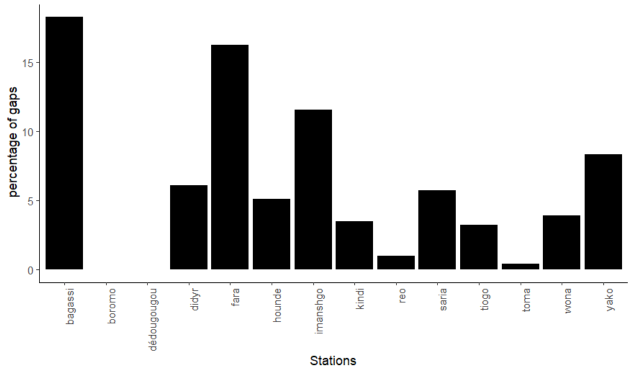


Figure 2: Percentage of raw data gaps by station

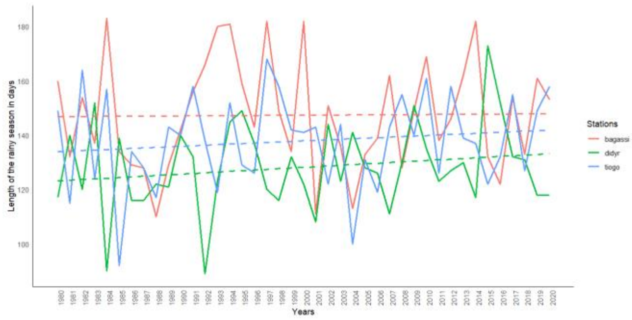


Figure 3: Change in the length of the rainy season from 1980 to 2020

2.2.2. Methodology

2.2.2.1 Length of rainy season

It's a question of determining the period of the rainy season. It is linked to the start date of the season and the end date of the season. Among the methods for determining the length of the rainy season, the statistical method (Ibrahim *et al.* 2012) was used over the period 1980-2020 for all stations in the study area. It can be formulated as follows:

- The start date of the season is the day on which 5% of the cumulative annual rainfall occurs,

- The end date of the season is the day on which 95% of the cumulative annual rainfall occurs.

2.2.2.2 Rainfall indices

To analyze the frequency of rainfall events, a number of rainfall indices were used. Their values were defined by the Expert Team on Climate Change Detection Monitoring and Indices (ETCCDMI) of the World Meteorological Organization (WMO), which recommends a series of indices for monitoring climate change (**Table 1**).

Table 1: Rainfall indices studied

Index name	Definition	Application
P0,1	Annual number of rainy days	P >= 0,1 mm/day
P0,1-5	Annual number of rainy days between 0.1 and 5 mm/day	P ε]0,1-5mm/day]
P5-15	Annual number of rainy days between 5 and 15 mm/day	P ε] 5-15mm/day]
P15-30	Annual number of rainy days between 15 and 30 mm/day	P ε]15-30mm/day]
P30-50	Annual number of rainy days between 30 and 50 mm/day	P ε]30-50mm/day]
P50	Annual number of rainy days exceeding 50 mm/day	P > 50mm/day

2.2.2.3 Cumulative annual rainfall

To determine the nature of the season for a given year **i** (wet or dry), we need to compare the annual rainfall for that year **i** with the average annual rainfall over a reference period. This is generally characterized by the interannual variation of the rainfall index **I_i** (Ali & Lebel, 2009). It indicates whether a year **i** is in deficit (**I_i<0**) or surplus (**I_i>0**). Equation 1 expresses this index as a function of rainfall, mean and standard deviation for the period under consideration.

$$I_i = \frac{P_i - \bar{x}}{\sigma} \quad (1)$$

Where **P_i** the annual rainfall for year **i**, $\bar{x}$ the average rainfall over the reference period (1980 to 2020), **σ** the standard deviation of annual rainfall over the reference period, **I_i** the rainfall index for year **i**. The annual rainfall index was calculated over the reference period. The Boromo synoptic station and the Didyr, Imasgo, Toma and Tiogo rainfall stations, representative of the study area, were chosen to characterize the variability of annual rainfall totals in the upstream Lower Mouhoun basin.

2.2.2.4 Statistical tests

In statistics, several non-parametric tests can be used to determine trends in a time series. The aim of trend analysis is to determine whether there is a significant change in the series. The Mann Kendall test (Kendall, Weber, 1975; Mann, 1945) was used to determine the level of trend significance in the rainfall series analyzed (Pohlert, 2023).

Let **x_1, x_2, ... x_n** be a series of data. The Mann Kendall statistic is defined by equations 2 and 3:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \mathrm{sgn}(xj - xi) \quad (2)$$

Where

$$\begin{cases} sgn(xj - xi) = 1,\ if\ (xj - xi) > 0 \\ sgn(xj - xi) = 0,\ if\ (xj - xi) = 0 \\ sgn(xj - xi) = -1,\ if\ (xj - xi) < 0 \end{cases} \quad (3)$$

With **xj** the annual rainfall corresponding to year **j**, **xi** the annual rainfall corresponding to year i. Assuming that the data are independent and identically distributed, we have E(S) = 0 (Kendall, 1948) and variance of the series is calculated from equation 4:

$$\mathrm{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} ti(ti-1)(2ti+5) \right] \quad (4)$$

Where n is the number of years, m is the number of groups of data linked by ties (consecutive equal values), and ti is the number of elements in the jth group of ties. When the sample size contains at least ten data, the distribution of the Z statistic is approximated by a centered reduced Gaussian distribution, illustrated by the fifth equation:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}},\ if\ S > 0 \\ 0,\ if\ S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}},\ if\ S < 0 \end{cases} \quad (5)$$

The null hypothesis H0 (no significant trend) is rejected when the degree of significance (p-value) is greater than a significance level set at 5%.

The Pettitt test has been used to evaluate abrupt changes or significant breaks (Pettitt, 1979). A non-stationary rainfall series shows a break characterized by a variation in the mean.

The season starts earlier in Bagassi, Boromo, Houndé and Fara, on the 128th, 127th, 123rd and 123rd days of the year respectively (**Figure 5**).

The end-of-season date is longest in Boromo, Dédougou, Fara and Kindi, where it occurs on the average 274th, 273rd, 275th and 272nd days of the year respectively (**Figure 6**).

Application of the Pettitt test is based on classification of the associated probability (AP) (Paturel *et al.* 1977). A break can be highly significant (PA<1%), significant (1%<PA<5%) or insignificant (5%<PA<20%). When PA>20%, the rainfall series is considered homogeneous (Drouiche *et al.* 2019). This is a non-parametric test derived from the Man-Whitney test. The null hypothesis H0 corresponds to the absence of a break in the series. The existence of a break corresponds to the alternative hypothesis. Equation 6 is used to determine the test statistic :

If the U test statistic is above the critical value for a given significance level, the null hypothesis is rejected. This means that there is a significant change in annual precipitation at a given significance level. Otherwise, there is insufficient evidence to conclude that there has been a significant change. All operations were performed on R and Excel 2016.

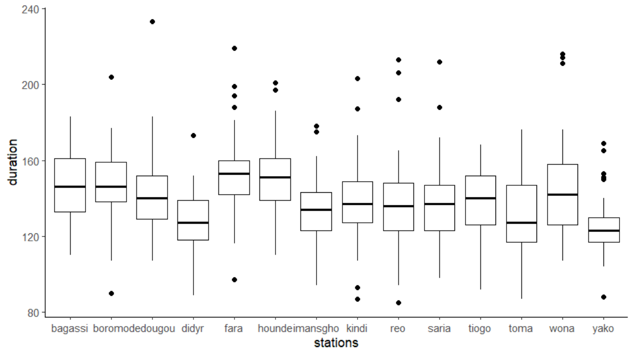


Figure 4: Boxplot of season length in days from 1980 to 2020

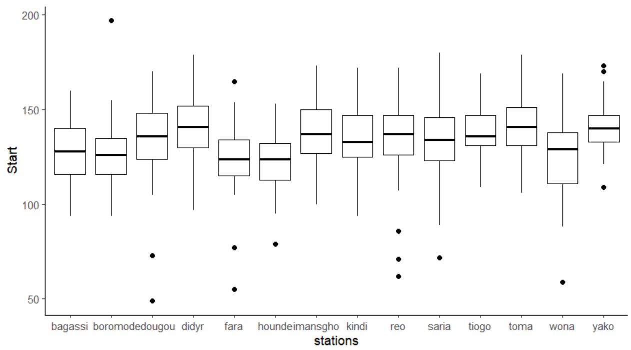


Figure 5: Boxplot of season start date in days from 1980 to 2020

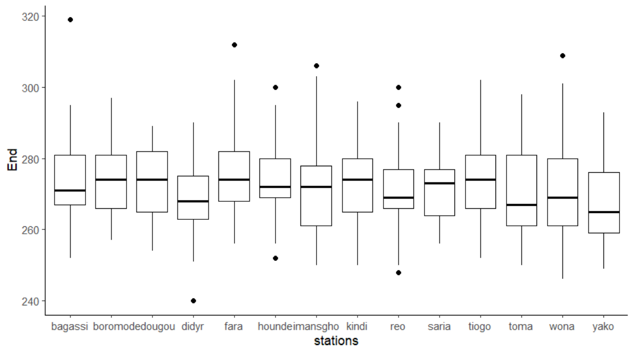


Figure 6: Boxplot of season end date in days from 1980 to 2020

$$U = \max_{1 \le j \le n} \sum_{i=1}^{j} \sum_{k=j+1}^{n} \operatorname{sgn}(\mathrm{xi} - \mathrm{xk}) \qquad (6)$$

Where xi, xk are the precipitation for years i and k, n is the total number of years and sgn is the sign function.

3. Results and discussions

3.1. Rainy season characteristics

Determining the length of the rainy season using the statistical method revealed variability by locality over the period 1980 to 2020. In Tiogo, Didyr, for example, the length of the season has lengthened (**Figure 3**). It is stationary in Bagassi.

A reduction in duration was observed in the remaining eleven localities. Boromo saw a 7.8% drop in duration between the 1980-2000 and 2001-2020 inter-annual averages. Season start dates are up at twelve stations. Season end dates are up at eight stations. The average length of the season over the period 1980-2020 is longer in Bagassi, Boromo, Houndé and Fara, where it occurs on the 147th, 148th, 153rd and 154th days of the year respectively (**Figure 4**).

3.2. Interannual rainfall variability

Analysis of inter-annual rainfall variability by plotting trends in the standardized rainfall index and the moving average across the Mouhoun sub-basin shows two rainy periods (**Figure 7**): 1980-1999 and 2000-2020. The results for Boromo, Didyr, Tiogo, Toma and Imasgo are shown in **Figure 8**. Both rainy periods are surplus. The first period of surplus rainfall saw a few periods of deficit (1980-1987 and 1989, 1990, 1992, 1995 in Boromo, 1980-1988 in Tiogo; 1982-1987 and 1990,1991,1992, 1993, 1996, 1997 in Toma; 1980, 1982, 1984, 1985, 1987, 1988, 1990, 1992, 1993,1997, 2000 in Imasgo; 1980 to 1985 and 1988, 1989, 1991, 1992, 1996, 1997, 1999 in Didyr). The second surplus period, with fewer dry spells and longer wet spells.

Variability in rainfall is apparent at all stations, with an upward trend over the rainy season between 1980 and 2020 in twelve localities. The Boromo, Tiogo, Didyr, Toma and Imasgo stations show an increase of 10 to 12.35% after the break year. A downward trend from 4.42% to 3.94% was noted in the Houndé and Wona stations respectively after the year of disruption. At the Boromo station, the series average is 810.94 mm (**Figure 8**). Use of the Man Kendall test on the annual precipitation series for the Boromo and Didyr stations revealed that the trend is statistically significant at the 5% threshold (**Table 2**). It is not significant for the Imasgo, Tiogo and Toma stations. For the Pettitt test, two insignificant breaks were found at Boromo and Imasgo respectively. It is considered homogeneous at Didyr, Tiogo and Toma (**Table 3**).

3.3. Trends in rainfall indices

The annual number of rainy days rose in nine localities (Boromo, Tiogo, Bagassi, Dédougou, Houndé, Réo, Saria, Kindi and Yako) and fell in the remaining five between 1980 and 2020. At the Fara, Imasgo and Toma stations, a decline of 20.29%, 3.76% and 6.12% respectively was recorded (**Figure 9**). An increase in the number of high-intensity rainy days (P>50 mm/dr) was recorded at eleven stations, with a slight decrease at Bagassi, Wona and Yako. The number of low-intensity rainfall days (P<5mm/day) also rose in ten localities, and fell in the remaining four. The number of rainy days between 5 and 15 mm/day increased in five localities, and decreased in nine. The number of rainy days between 15 and 30 mm/day increased in five localities, and decreased in the remaining nine. The number of rainy days between 15 and 30 mm/day is up in ten localities and down in the remaining four.

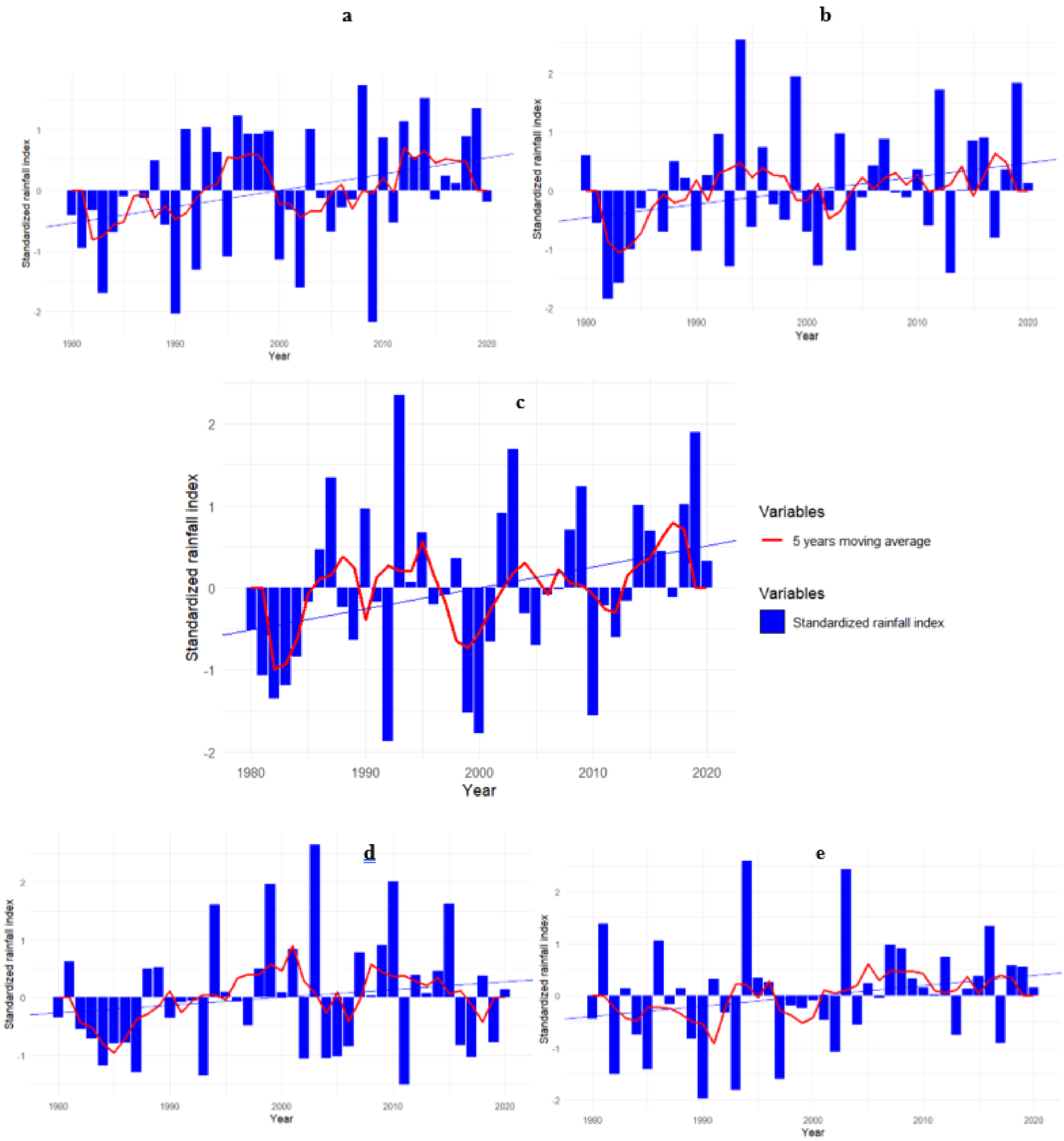


Figure 7: Interannual variation in standardized rainfall indices for five stations (a-Boromo, b-Tiogo, c-Didyr, d-Toma, e-Imasgo) over the period 1980 to 2020

The analysis of rainfall trend variability was carried out in the rainy season period between 1980 and 2020. Season duration is decreasing in most localities. The rainfall pattern in the lower Mouhoun upstream basin shows season variability (dry or wet), with an overall trend towards higher annual rainfall between 1980 and 2020. A general trend towards an increase in the frequency of high-intensity rainfall (P>50mm/dr) and low-intensity rainfall (P<5mm/dr) in the basin. The annual number of rainy days is also increasing. This evolution translates into an increase in the frequency of heavy rainfall causing flooding in the study area, with enormous consequences for agricultural production during the period. The increased frequency of light rains can lead to a delay in crop growth. This poor distribution of rain during the rainy season creates enormous disruption to the development of agricultural produce, resulting in lower yields and the displacement of populations to more favorable areas.

A number of authors have studied climate variability in the Mouhoun basin. Some works can be cited in comparison with our work. Farmers in the basin have suffered enormous economic losses due to this variability. Indeed, the area is renowned for its susceptibility to flooding and water shortages, leading to population migration and crop failure (Simonsson, 2005). These results are consistent with our own work, which illustrates the increasing frequency of heavy rainfall (rainfall greater than 50 mm/dr). The sixth IPCC report predicts an increase in extreme climatic events in West Africa. The increase in intense rainfall is expected to average 15% over the period 2021-2050 in Burkina Faso (Ibrahim *et al.* 2012). An increase in temperature of 0.9 ^{o} C and a variation in annual precipitation of -3% to 16% is forecast in the Mouhoun basin for the end of the 21st century (Aziz & Obuobie, 2017). In the Dano basin, a sub-catchment of the Mouhoun, simulations show an improvement in water supply between the periods 1900-2005 and 2006-2032 (Felix *et al.* 2019). These results show an increase in the amount of precipitation in the Mouhoun basin. However, rainfall breaks and trends are not highlighted in most of his work through the use of statistical tests to determine the level of significance. The increase in annual rainfall in our study area can be explained by the high frequency of heavy rains, resulting in poor rainfall distribution across the seasons.

Table 2: Results of the Mann-Kendall test applied to annual precipitation

Stations	Test statistic Z	p-value	Null hypothesis
Boromo	0,228	0,037	Accepted
Didyr	0,241	0,027	Accepted
Imasgo	0,195	0,074	Refused
Toma	0,11	0,317	Refused
Tiogo	0,205	0,061	Refused

Table 3: Results of the Pettitt test applied to annual precipitation

Parameters	Boromo	Didyr	Imasgo	Tiogo	Toma
Year of breakup	1992	2001	2002	1990	1993
Test statistic	165	158	184	128	124
Average before breakage (mm)	739,75	643,49	667,35	661,78	606,18
Average after breakage (mm)	843,99	725,92	741,54	741,58	690,1
p value	0,199	0,24	0,113	0,497	0,541
Variation in precipitation (%)	12,35	11,36	10	10,76	12,16

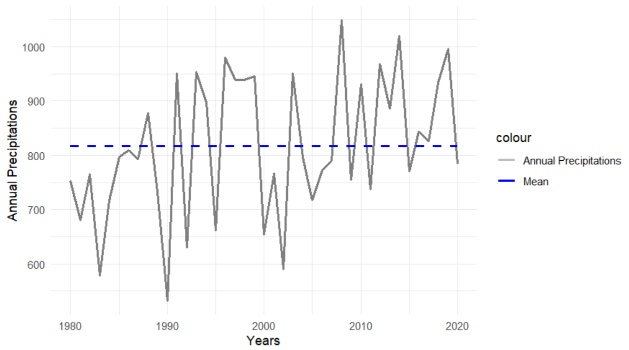


Figure 8: Annual precipitation during the rainy season at the Boromo station

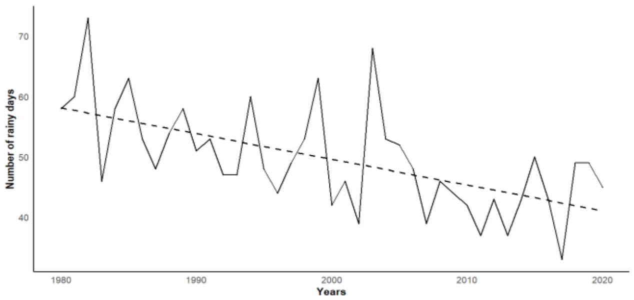


Figure 9: Annual number of rainy days at the Fara station

4. Conclusion

The aim of this study was to characterize rainfall variability in a Mouhoun sub-basin during the rainy season. Cumulative annual rainfall is defined by a variation of dry and wet periods, with a general upward trend between 1980 and 2020. There has been a reduction in the length of the rainy season, an increase in the number of rainy days and an increase in rainfall extremes at most stations. Annual precipitation increased by 10 to 12.35 % after the year of disruption. This change in regime has had numerous impacts on the speculative activities of farmers in the basin. These include the destruction of harvests, the failure of certain crops to reach maturity, and the displacement of the population to more favorable environments. Despite a trend towards higher annual rainfall, the length of the dry season is increasing at most stations.

Based on these observations, the future behavior of rainfall in the Mouhoun basin through hydrological modelling would enable us to determine its impact on water resources. An inventory of agricultural practices in the study area could also be carried out in order to propose an adaptation strategy in the light of this worrying situation, with a view to optimizing crop yields despite unfavorable climatic conditions.

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