Analysis of rainfall dynamics in the three main cities of northern Cameroon

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Abstract

The northern zone of Cameroon, which depends mainly on agriculture, is considered one of the most vulnerable regions in the country to climate change. Few studies based on field data have examined the changes in climatic conditions that affect agriculture. This research focuses on fluctuations in precipitation that determine dry and wet seasons. From 1973 to 2020, data were collected from meteorological stations located in three major cities in northern Cameroon: Ngaoundere, Garoua and Maroua. Data were tested for homogeneity using the Pettitt and Buishand tests. Trends were analyzed using the Mann-Kendall test, Sen's slope estimator and the regression line, while drought severity was assessed using the standardized rainfall index method. These data homogeneity tests were performed using two statistical tools, SPSS and XLSTA software. According to the Pettitt's test, rainfall increased by 29.6% in Ngaoundere from 1997 to 2020, compared to the previous years of 1973–1996; in Garoua, rainfall increased by 36.2% from 1988 to 2020, compared to the previous years of 1973–1987. However, from 1973 to 2020, the average rainfall in Maroua remained stable around 716.5 mm, with a decreasing trend according to the Mann-Kendall test. In conclusion, this study shows that rainfall has increased significantly in the cities of Ngaoundere and Garoua, making these areas favorable for seasonal and market gardening. However, in Maroua, caution is advised, as rainfall is reportedly decreasing in this locality, increasing the risk of food insecurity. A credible climate alert system must be implemented on a broad scale to guide farmers.

1 Introduction

The northern part of Cameroon includes three regions which are Adamawa (Ngaoundere as its capital), the Far North (Maroua as its capital) and (North with Garoua) as its capital. Bring et al. (2016), present this part of Cameroon as one of the most vulnerable areas of the country to climate change, due to a severe lack of reforestation and the advancement of the desert, among other things. The Far North and North Regions have undergone one of the most drastic degradation of 90% of its surface area in recent decades, and the Adamawa Region is also affected by degradation and rapid drought, according to Bring et al. (2020). According to the Intergovernmental Panel on Climate Change (IPCC) (Parry et al. 2007), the manifestations of climate change at the global level might result in, among other things, a rise in rainfall, sea level, and an increase in the frequency and intensity of extreme events (droughts, floods, cyclones). At the regional level, each continent, depending on its specific biophysical and human characteristics, is already undergoing these changes. According to Seneviratne et al. (2012), Africa in general would be one of the most exposed continents to these climatic risks and the Sahel zone, where the northern part of Cameroon is located, stands out as one of the most affected by extreme events (rainfall instability, floods, water shortage, drought progression, etc.).Accordingly, Challinor et al. (2007) also reports that Africa could indeed be considered one of the most vulnerable continents to the effects of climate variability and change, due to its high dependence on climate-dependent agriculture, which plays a major role in supporting rural livelihoods and economic growth; The same argument of the continent's vulnerability is supported by Olivier Beucher et al. (2012); he estimated that Africa, although emitting less greenhouse gases (GHG) with a minimum emission rate of 4% and 2.5% of global CO_2, would nevertheless be the most vulnerable continent to climate shocks, and whose precipitation would decrease in the Mediterranean and Southern Africa.

Pierre Camberlin (2007) specifies that the evaluation of the modalities of possible climate changes that affect or will affect an area, assumes a good knowledge of the functioning of its climate. Therefore, Niasse et al. (2004) define the concept of climate variability and change as the modification or significant variation of the climate, whether natural or due to factors of anthropogenic origin. Another definition is also given by Mitosek (1992), which states that climate variability would refer to the variability inherent in the stochastic stationary process that approximates the climate on the scale of a few decades; and of which precipitation would be among the first four priority variables in the assessment of climate variations. Ouarda et al (1996) report that Kite and Harvey (1992) also identified other variables, such as evaporation, vegetation, soil moisture, management of hydraulic structures, timing of extreme events, water quality indices, and glacier conditions as factors to be considered in the analysis and understanding of climate change. According to the World Meteorological Organization (WMO) and echoed by Mbog et al. (2020), climate is the average or typical weather condition observed over a long period of at least 30 years for a given geographical location; however, Nefzi (2012), recalls that experts have considered that the 30-year interval defining the period for an estimate of normal climate, is not only too short to return the trend of the climate in a given region, but also too long to decipher the anomalies and inter-annual variabilities.

Several organizations, e.g The World Bank (2021), monitor the evolution of climatic conditions in Cameroon using some reference data, derived from default data, classified according to climatic zones derived from the Köppen-Geiger climate classification system, which divides climates into five climatic groups of which rainfall is one of the main parameters. According to MINEPDED (*Ministry of the Environment, Nature Protection and Sustainable Development*) et al. (2015), in Cameroon, observations of climate change indicate a decrease in rainfall in four of the five agro-ecological zones in the country (high Guinean savannahs, Sudano-Sahelian, high plateaus, and bimodal rainfall), with the exception of the monomodal rainfall zone, where rainfall has increased. Servat et al. (1999) mention that, in Cameroon, during the period of disruption from 1969 to 1971, the average rainfall deficit observed was 16%; and this rainfall deficit was already being felt and would even seem to have increased over more than two decades from the 1970s to 1980. According to Gaymard et al. (2015), Cameroon is already experiencing the various effects of climate change and by the year 2100, the desert will dominate in the northern Cameroon zone, if nothing is done; the authors also note that in the Sudan-Sahelian zone, the projected changes in rainfall will range from − 12 mm to + 20 mm per month (-8–17%) by the year 2090. Bassirou et al. (2022), report that a decrease in rainfall would significantly affect agricultural productivity, and that the phenomenon of climate change is a reality in Cameroon and therefore poses a serious threat to Cameroonian agro-industries.

However, in Cameroon, scientific publications reporting on the analysis of the evolution of certain climatic parameters in localities remain insufficient, as pointed out by Kaah (2017), who indicates that very few analyses of daily rainfall and temperature data have been carried out in Cameroon due, among other things, to the difficulty of accessing different meteorological field data; This argument is also supported by Sotamenou et al. (2013), who report the problem of unavailability of data during their study in the southern part of Cameroon, where the study had a small inter-temporal dimension (10 years) due to the absence of available data. In the same vein, Saha (2019) notes that because of the problem of availability of long-term data on both climatic and hydrological parameters, decision-making for preventive actions against natural hazards would not be sufficiently informed, and that it would be difficult to establish the rainfall profile in the Sudano-Sahelian zone in Cameroon in particular.

In this context of difficult access to data, and contrary to studies where the data or part of the data would be derived from global or default data (Nicholson et al. 2018; Pascal et al. 2022; Molua 2006), to name but a few, the present study is based on updated field data available from ASECNA and CCAA weather stations. It covers the period from 1973 to 2020 with an inter-temporal dimension of 48 years.

After the description of the study framework and methodology (Section 2), including the study framework (Section 2.1) and methodology (Section 2. 2), the results are presented in Section 3, which deals with the evolution and variations of annual and monthly rainfall, considering separately the locality of Ngaoundere, in the Adamawa Region (Section 3.1); the locality of Garoua, in the Northern Region (Section 3.2); and the locality of Maroua, in the Extreme North Region (Section 3.2). However, it should be noted that the causes of these variabilities are beyond the scope of this paper. A discussion of annual and monthly trends in the different localities follows (Section 4). Section 5 recalls the observed trends and suggests areas where further research is needed.

2 Location Of The Study Areas And Methodology

2.1 Location of the study

The present study was conducted in the three main towns of the northern regions (Fig. 1), representing two of Cameroon's five agro-ecological zones. These zones correspond administratively to the Regions of Adamawa (high savannah zone located at latitude 7.35°N, longitude 13.56°E and analtitude of 1114 meters) with a surface area of 17,196 km²; the northern Region located at latitude 9.33°N, longitude 13.38°E and an altitude of 242 meters with an area of 13,614 km² and the Far North region located at latitude 10.45°N, longitude 14.25°E and an altitude of 423 meters (Sudano-Sahelian zone) with an area of 4,665 km².

2.2 Methodology

2.2.1 Data collection

The monthly and annual climate data for the meteorological stations studied come from the Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA) operating in the Adamawa and North Regions, namely meteorological station 64870 (FKKN) and meteorological station 64860 (FKKR) in Ngaoundere and Garoua, respectively; as for the data from the Far North Region, they come from meteorological station 64851 (FKKA) managed by the Cameroon Civil Aviation Authority (CCAA) in Maroua. This study is based on rainfall data; the observation period extends over forty-eight years (48 years), i.e., from 1973 to 2020 (Table 1); this gives the opportunity to conduct a set of statistical tests to bring out the useful information to be capitalized on. However, the observation shows a low availability of research data in Cameroon compared to West African countries (Benin, Senegal, and Burkina-Faso).

Table 1
Observation stations studied

Stations	Latitude	Longitude	Altitude	Period of observation
Adamawa (Ngaoundere)	7.35°N	13.56°E	1114 m	1973–2020
North (Garoua)	9.33°N	13.38°E	242 m	1973–2020
Far-North (Maroua)	10.45°N	14.25°E	423 m	1973–2020

The monthly data collected in the different stations allow obtaining the total annual precipitation for each station, based on the following equations:

$$\begin{cases} Pm = \Sigma(\mathrm{Px}) \\ and \\ Na = \Sigma(\mathrm{Ny}) \end{cases}$$

1

Where:

Pm = monthly or annual rainfall in mm.

Px = monthly or annual volume of rainfall collected at weather stations in mm.

Na = monthly or annual number of rainfall days

Ny = monthly or annual number of days of rainfall recorded for the weather stations.

In this study, data processing is based SPSS Statistics version 20, Excel 2016, XLSTAT.

2.2.2 Statistical tests

The analysis was based on certain statistical tools to assess the homogeneity of the data in one hand and on the other hand to evaluate the null hypothesis of absence of rupture. For this purpose, a statistical approach was used, including the tests proposed by Student, Welch, Pettitt and Buishand. But beforehand, the variance tests were carried out thanks to the test proposed by Fisher; and to test the null hypothesis of absence of trend, a statistical approach was adopted, including the test proposed by Mann-Kendall.

2.2.2.3 Pettitt Test

The Pettitt non-parametric test is commonly applied to detect a single point of change in hydrological or climatic series with continuous data (Pohlert 2020) Pettitt considers a sequence of independent random variables X_1, X_2,... X_N. The sequence is assumed to contain a breakpoint at τ if the X_t for t = 1 ... τ have a common distribution F1 (X), and the X_t, for t = τ + 1... N have a common distribution F_2(X), different from F_1(X). The null hypothesis of "non-breakage" H0: τ = N (2)

The alternative hypothesis of "rupture"

H1: 1 ≤ τ < N (3)

A non-parametric statistical test is used to test this equation; and no particular condition is required for the functional forms of F1 and F2 except for continuity (Lubes-Niel et al. 1998).

$$ifD_{ij} = sign\left(X_i - X_j\right)$$

4

$$sign(X) = 1 if X > 0; 0 if X = 0 and - 1 if X < 0$$

5

,

Then the variable

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=1+1}^{N} D_{ij}$$

6

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=1+1}^{N} sign\left(x_i - x_j\right)$$

7

The U_t, N statistic is considered for values of t between 1 and N. To test H0 against H1, Pettitt proposes to use the variable:

$$K_N = \max_{1 \leq t < N} \left(\left|U_{t,N}\right|\right)$$

8

Using rank theory, Pettitt gives the approximate probability of exceeding a k value by:

$$Prob(K_N > K) \approx 2\exp\left\{-\frac{6K_N^2}{N^3 + N^2}\right\}$$

9

For a given first-species risk α, H0 is rejected if this probability is less than α. In this case, the series has a break at time t = τ defining K_N. The test is most sensitive to a change in mean.

2.2.2.4 Buishand Test

The Buishand test is a parametric test whose statistic is defined from the maximum of the cumulative sum of the deviations from the mean or the median. It is a test for detecting a temporal break in a data series. The alternative hypothesis of this test being an abrupt change in the mean, the power function is estimated by generating series from independent normal variables of the same variance but with a break in the mean from a randomly chosen date (Doukpolo 2014).

According to Lang et al. (2003), the Buishand statistic is derived from an original formulation given by Gardner in 1969; this Gardner statistic is used for a two-sided mean break test at an unknown time and is written:

$$G = \sum_{k=1}^{p-1} P_k \left\{ \frac{S_k}{\sigma_x} \right\}^2$$

10

(11)

P_k denotes the a priori probability that the break occurs just after the k^{th} observation.

This formulation assumes that the variance σ_x^2 is known. If it is unknown, it can be replaced by the sample variance D^2x and if P_k is chosen to be uniform, we finally obtain the statistic U defined by Lang et al. (2003):

$$U = \frac{\sum_{i=1}^{N-1} \left(\frac{S_k}{D_x} \right)^2}{N(N+1)} \quad (12)$$

$${ {D}^{2}}_{x}=\sum _{i=1}^{N} \left(\stackrel{-}{{X}_{i}}-\stackrel{-}{{X}_{1}}\right)^2 / N \quad (13)$$

2.2.2.5 Mann-Kendall Test

The Mann-Kendall test, proposed by Mann (1945) and Kendall (1975), is a non-parametric test commonly used to detect monotonic trends in environmental, climatic or hydrological data series (Pohlert 2020). The null hypothesis, H0, is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis (Ha) is that the data follow a monotonic trend. The analysis of the trends will only be considered as representative when they are statistically significant at the 0.05 threshold, i.e. 5%, according to the non-parametric Mann-Kendall test (Yue et al.2002). This test was applied to time series of precipitation anomalies. The Mann-Kendall test is calculated as follows (Drouiche et al. 2019):

$$S=\sum _{k=1}^{N-1} \sum _{j=k+1}^{N}sign \left({ X}_{j}-{ X}_{k}\right)$$

14

$$sign \left(x\right)=\left\{\begin{array}{c}1 \text{ if } x>0\\ 0 \text{ if } x=0\\ -1 \text{ if } x<0\end{array}\right.$$

15

$$\left\{\begin{array}{c} \\ \\ sign \left({ X}_{j}-{ X}_{k}\right)=1, \text{ if } \left({ X}_{j}-{ X}_{k}\right)>0\\ \\ sign \left({ X}_{j}-{ X}_{k}\right)=0, \text{ if } \left({ X}_{j}-{ X}_{k}\right)=0\\ \\ sign \left({ X}_{j}-{ X}_{k}\right)=-1, \text{ if } \left({ X}_{j}-{ X}_{k}\right)<0\\ \\ \end{array}\right.$$

16

Assuming the data are independent and identically distributed, Kendall (1975) gives E(S) = 0 and the variance Var (S) is:

$$Var\left(S\right)=\left\{n\left(n-1\right)\left(2n+5\right)-\sum _{j=1}^{p}{ t}_{j}({ t}_{j}-1)(2{ t}_{j}+5)\right\}/18$$

17

Where n is the number of data in the series, p is the number of related groups, and tj is the number of data in the group of order j. If the sample contains ten or more data, the distribution of the test statistic Z below will be approximated by a center-reduced Gaussian.

$$Z=\left\{\begin{array}{c} \\ \\ \frac{S-1}{\sqrt{Var \left(S\right)}}, \text{ if } S>0\\ \\ 0, \text{ if } S=0\\ \\ \frac{S+1}{\sqrt{Var \left(S\right)}}, \text{ if } S<0\\ \\ \end{array}\right.$$

18

The S statistic is closely related to Kendall's τ given by:

$${\tau }=\frac{S}{D}$$

19

$$D=[\frac{1}{2}n\left(n-1\right)-\frac{1}{2}\sum _{j=1}^{p}{ t}_{j}({ t}_{j}-1)\left]{ }^{\frac{1}{2}} \right[\frac{1}{2}n(n-1)]{ }^{\frac{1}{2}}$$

20

2.2.3 Sen's Slope

Sen's slope is estimated by Sen's method, which is a nonparametric procedure developed by Sen in 1968 (Pranab Kumar Sen 1968); this slope is the median of all slopes computed between each pair of points (ti, Yi) and (tj, Yj); the set S of N distinct pairs (i, j) for which ti < tj,; and for which ${ X}_{ij}$is an estimate of the slope calculated as follows:

$${ X}_{ij}=\left\{\frac{{ Y}_{j}-{ Y}_{i}}{{ t}_{j}-{ t}_{i}}\right\} , (i, j) \in S \quad (21)$$

According to Fawaz et al. (2020), the Sen Slope estimator proves to be a powerful tool for developing linear relationships; and of which this Sen Slope has the advantage over the regression slope in that coarse data series errors and outliers do not affect it much. A positive Sen Slope indicates an upward trend, while a negative Sen Slope suggests a downward trend.

2.2.6 Analysis of rainfall indices

The analysis of the standard deviation (indicator of climatic variability) allows to evaluate the dispersion of the values around the mean. This standard deviation is determined by the following formula:

$$\sigma \left(\text{x}\right)=\sqrt{v} \quad (22)$$

Where $\sigma \left(\text{x}\right)$ and v represent respectively the standard deviation and the variance.

From the standard deviation, the monthly and interannual reduced rainfall centered anomalies are calculated. The anomalies of the different parameters are calculated by the formula:

$$IP=\frac{{X}_{i}-\stackrel{-}{X}}{\sigma \left(x\right)} \quad (23)$$

Where IP is the centered reduced anomaly for year i; X_i is the value of the variable (precipitation); $\stackrel{-}{X}$ is the series mean and σ(x) is the series standard deviation. A drought occurs when the index continuously has a negative value of -1.0 or less and ends when the index becomes positive (Svoboda et al. 2012); and Table 2 below shows the values of the intensity of drought events as a function of the index value.

Table 2
Values of the normalized precipitation index (Svoboda et al. 2012)

2.0 and above	**Extremely wet**
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately Wet
0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Very dry
− 2 and below	Extremely dry

2.2.7 Analysis of data homogeneity

The analysis of the homogeneity of the data is carried out using two statistical tools, namely SPSS and XLSTAT. The method consisted in dividing our observation series (1973 to 2020) into two samples of equal size (1973 to 1996; and 1997 to 2020); then seeking to compare the two averages of each sample, with the aim of verifying the existence of a significant variability between the two samples. In order to perform a Comparison of Means Test, it is very interesting to first perform a Comparison of Variance Test (Fisher Test). If at the end of the Fisher Test, there is equality of variances, we use the Student Test to compare the means; in the opposite case of inequality of variances, we use the Welch Test to compare the means. In fine, after these tests, the equality of the means between the two samples shows more or less homogeneity of our data. Furthermore, we use two tests, namely the Pettitt test and the Buishand test, to test the homogeneity of the global sample (1973 to 2020).

3 Results

The statistical analysis of the data reveals that the data arranged in the different study areas are remarkably homogeneous in the majority of cases. This allows validating the quality of the data collected.

3.1 Evolution and variation of rainfall in the Ngaoundere region

Figure 2 below shows the evolution of rainfall in Ngaoundere from 1973 to 2020. It follows from this analysis that rainfall over these 48 years has fluctuated; the trends are positive, as the linear regression analysis shows an interannual increase in rainfall. It should be noted that the R^2 values = 0.2558 reflects a significant variation depending on the years; therefore, the maximum precipitation during this study is recorded in 1982 with a value of 3,447 mm, followed by the year 2020 with a value of 2,292 mm; and the lowest precipitation was recorded in 1975, with a value of 26 mm of rainfall.

3.1.1 Rainfall data breaking tests

After conducting break tests of the rainfall series of the parent sample taken between 1973–2020, i.e. 48 years in Ngaoundere, it appears that the series shows a break at the date of 1996 with the Pettitt test and in 1981 with the Buishand test; because, given that the calculated p-value ((P-Value of the Pettitt Test = 0.0043 < 0.05 (5%) ; P-Value of Buishand's Test = 0.0046 < 0.05 (5%)) calculated is lower than the level of significance alpha = 0.05, the null hypothesis H0 must be rejected, and the alternative hypothesis Ha retained "There is a date from which there is a change in the data, and from which there is a break in the series"; see Fig. 3 (a-b) below.

According to the Pettitt's test, in Ngaoundere, rainfall has increased by 448 mm over the period 1997 to 2020 compared to the previous period 1973 to 1996, when the average rainfall was 1068 mm between 1973 and 1996, and this value would have increased to 1568 mm between 1997 and 2020 (from 1997–2020, rainfall would have increased by 29.6% compared to the previous year's 1973–1996). However, the Buishand test indicates an increase in precipitation of 850.8 mm over the period 1982 to 2020 compared to the previous period 1973 to pre-1981 period where the average precipitation was 601.2 mm between 1973 and 1981, and this value would have increased to 1452 mm of 1982 to 2020 (from 1982–2020, precipitation would have increased by 58.6% compared to the years prior to 1973–1981).

3.1.2 Anomalies in rainfall

The data analysis reveals that rainfall in Ngaoundere over the period 1973–2020 (48 years) shows 31 wet years and 17 dry years, see Fig. 4 below. The wet years have six periods from 1987 to 1989, 1991 to 2000, 2002 to 2006, 2008 to 2010, 2012 to 2014, and 2016 to 2020; and two dry periods from 1973 to 1981 and 1984 to 1986, respectively. Also noted is the presence of wet and dry years in the above periods: this is the case of the years 1982, 1983, 1990, 2001, 2007, 2011 and 2015. From 1973 to 2020, the trend is positive. The linear regression analysis shows an interannual increase in precipitation from 1973 to 2020. It should be noted that the R2 value = 0.2558 shows a significant variation of precipitation depending on the year. From this analysis, it appears that the extremely dry years are: 1973 to 1976, 1985 and 1987 because their rainfall index is -2; the years 1979, 1981 and 1986 were moderately dry, because their rainfall index is -1; however, the years 1983, 1997, 1999, 2016, 2018 and 2019 were moderately wet with a rainfall index of 1 and finally the years 1982 and 2020 were extremely wet, because their rainfall indexes are 4 and 2 respectively.

3.1.3 Trend of rainfall data

After conducting the trend test for the rainfall series in Ngaoundere from the parent sample taken between 1973 and 2020, i.e. 48 years, it is clear that there is a trend in the rainfall series, and therefore significant variations are observed for this variable. Since the p-value of the Precipitation Trend Test (P-Value of the Precipitation Test = 0.0000066) calculated is below the significance level alpha = 0.05, the null hypothesis H0 must be rejected, and the alternative hypothesis Ha must be retained. "There are trends in the series" (e Fig. 5).

3.1.4 Monthly rainfall Variations

Figure 6 below presents the monthly variability of rainfall in Ngaoundere over the period from 1973 to 2020 (48 years), which is necessary to distinguish between wet and dry months; from this analysis, it appears that the climate in Ngaoundere is a humid tropical climate with two seasons: a long dry season that runs from November to March (5 months), a long wet season that runs from April to October (7 months); however, August is the wettest month, with an average rainfall of 239 mm; January is the driest month, with 0 mm of rainfall. .

3.2 Evolution and variation of rainfall in Garoua

Figure 7 below shows the evolution of rainfall in Garoua from 1973 to 2020. It follows from this analysis that rainfall over these 48 years has fluctuated; the trends are positive, as the linear regression analysis shows an inter-annual increase in rainfall. It should be noted that the R2 values = 0.3018 reflects a significant variation depending on the years; therefore, we note that the maximum precipitation during this study is recorded in 2008, with a value of 1,243 mm; and the lowest precipitation was recorded in 1974, with a value of 135 mm of rainfall.

3.2.1 Rainfall data breaking tests

After performing break tests on the rainfall series of the parent sample taken between 1973–2020, i.e. 48 years in Garoua, it appears that the series shows a break at the date of 1987; Since the calculated p-value ((P-Value of Pettitt's Test = P-Value of Buishand's Test = 0.0010 < 0.05 (5%)) is lower than the significance level alpha = 0.05, we must reject the null hypothesis H0, and retain the alternative hypothesis Ha "There is a date from which there is a change in the data, and from which there is a break in the series", see Fig. 8 (a and b). Furthermore, according to the Pettitt and Buishand tests, in Garoua, rainfall underwent a net increase of 366.3 mm from 1988 to 2020 compared to previous years where the average rainfall was 645.7 mm from 1973 to 1987 and increased to 1012 mm from 1988 to 2020 (from 1988–2020, precipitation would increase by 36.2% compared to the previous year's 1973–1987).

3.2.2 Anomalies in rainfall

This analysis shows that rainfall in Garoua over the period 1973–2020 (48 years) shows 31 wet years and 17 dry years, see Fig. 9 below. The wet years have 3 periods from 1973 to 2006, 2008 to 2010 and 2016 to 2018 respectively; and only one dry period from 1973 to 1977. Also note the presence of wet and dry years in the above periods: this is the case of the years 1978, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 2007, 2011, 2012, 2013, 2014, 2015 and 2020. From 1973 to 2020, the trend is positive. The linear regression analysis shows interannually an increase in precipitation from 1973 to 2020. It should be noted that the R2 value = 0.3018 reflects a significant variation in precipitation over the years. From this analysis, it appears that the extremely dry years are: 1973 to 1976, and 1979, as their rainfall indices vary between − 2 and − 3; the years 1977, 1983, 1985 and 2011 were moderately dry, as their rainfall index is -1; however, the years 1981, 1988, 1990, 1991, 1993 to 1997, 1999, 2001, 2007, 2008 to 2010, 2012, 2017 to 2019 were moderately wet with a rainfall index of 1.

3.2.3 Trend of rainfall data

After conducting the trend test of the rainfall series in Garoua from the parent sample taken to 1973–2020, i.e., 48 years, it appears that there is a trend in rainfall, and therefore significant variations are observed for this variable. For, given that the p-value of the rainfall trend tests (P-Value of the rainfall test = 0.0019 < 0.05 (5%)) calculated is below the significance level alpha = 0.05, the null hypothesis, H0, must be rejected and the alternative hypothesis, Ha, retained. "There are trends in the series", see Fig. 10 below.

3.2.4 Monthly Rainfall Variations

Figure 11 below presents the monthly variability of rainfall in Garoua over the period from 1973 to 2020 (48 years), which is necessary to distinguish between wet and dry months; from this analysis, it appears that the climate in Garoua is a dry tropical climate with two seasons: a long dry season that runs from November to March (5 months), a long wet season that runs from April to October (7 months); however, August is the wettest month, with an average rainfall of 199 mm; December, January and February are the driest months, with 0 mm of rainfall..

3.3 Evolution and variation of rainfall in Maroua

Figure 12 below shows the evolution of rainfall in Maroua from 1973 to 2020. It follows from this analysis that rainfall over these 48 years has fluctuated; the trend is negative, as the linear regression analysis shows a small interannual downward variation in rainfall. It should be noted that the R2 values = 0.0086 reflects an absence of significant variation depending on the years; however, the maximum precipitation during this study is recorded in 1994, with a value of 1,194 mm of precipitation; and the lowest precipitation was recorded in 2019, with a value of 251 mm of precipitation

3.3.1 Rainfall data breaking tests

After performing break tests on the rainfall series of the parent sample taken to1973-2020, i.e. 48 years in Maroua, it appears that the series does not show any break. Because, given that the p-value ((P-Value of Pettitt's Test = 0.8604 > 0.05 (5%); P-Value of Buishand's Test = 0.6684 > 0.05 (5%)) calculated is higher than the significance level alpha = 0.05, the null hypothesis, H0, cannot be rejected; "the data are homogeneous, and there is no break in the series", see Fig. 13.

Furthermore, according to the Pettitt and Buishand tests, in Maroua, the average rainfall remains around 716.8 mm from 1973 to 2020, so no significant variation is observed.

3.3.2 Anomalies in Rainfall

This analysis shows that rainfall in Maroua over the period 1973–2020 (48 years) shows 31 wet years and 17 dry years, see Fig. 14. The wet years have 5 periods from 1975 to 1978, 1980 to 1982, 1988 to 1990, 1998 to 2010 and 2013 to 2015 respectively; and 2 dry periods from 1985 to 1987 and from 2016 to 2019, respectively. Also note the presence of wet and dry years in the above periods: this is the case of the years 1973, 1974, 1979, 1983, 1984, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 2011, 2012 and 2020. From 1973 to 2020, the trend is negative. The linear regression analysis shows interannually no increase in precipitation from 1973 to 2020. It should be noted that the R2 value = 0.0086 reflects a very small and insignificant variation in precipitation over the years. From this analysis, it appears that the extremely dry years are: 1979, 1987, 2016 and 2019 because their rainfall index is between − 2 and − 3; the years 1975, 1983, 1985, 1986, 1997 and 2013 were moderately dry, because their rainfall index is -1; however, the years 1978, 1992, 1995, 1999, 2003 and 2010 were moderately wet with an index of 1 and finally the years 1975, 1976, 1994 and 2020 were extremely wet, because their rainfall indexes are between 2 and 3.

3.3.3 Trend of rainfall data

After performing the trend test of the rainfall series in Maroua from the master sample taken between 1973–2020, i.e. 48 years, it appears that there is no trend in this series, and therefore no variation; ((P-Value of the Rainfall Test = 0.7023 > 0.05 (5%)) calculated is greater than the threshold significance level alpha = 0.05, The null hypothesis H0 cannot be rejected, "There is no trend in the series", see Fig. 15 below.

3.3.4 Monthly Rainfall Variations

Figure 16 below presents the monthly variability of rainfall in Maroua over the period from 1973 to 2020 (48 years), which is necessary to distinguish between wet and dry months; from this analysis, it appears that the climate in Maroua is a dry tropical Sahelian climate with two seasons: a long dry season that runs from November to March (5 months), a long wet season that runs from April to October (7 months); however, August is the wettest month, with an average rainfall of 218 mm; November, December, January, February and March are the driest months, with 1 mm of rainfall for the month of March and 0 mm for the other months.

4 Discussion

Figures 2, 7 and 12 show the evolution of rainfall in Ngaoundere, Garoua and Maroua respectively; The analysis of the results of the statistical tests illustrated in Figs. 3, 8 and 13 respectively in Ngaoundere, Garoua and Maroua, shows that the rainfall dynamics in these localities is globally unstable, with a tendency to increase in rainfall in Ngaoundere and Garoua according to Figs. 5 and 10; these findings are consistent with those reported by Amougou et al. (2015), Vondou et al. (2021), and Cheo et al. (2013).

Ngaoundere's increasing rainfall is most likely owing to its location, which is at an average altitude of 1114 meters in a humid Sudanese tropical environment that encourages greater rainfall. Our findings are also in line with those of Amougou et al. (2015), who claim that the strong climatic variations observed in different parts of the country are partly explained by disturbances in the North Atlantic, whose regular movements of air masses easily reach the entire country, causing significant disturbances; they also claim that the North Atlantic cooling causes an increase in rainfall in the Ngaoundere region.

According to Cheo et al. (2013), the increase in rainfall in Garoua is due to a rise in temperature, which increases the rate of evapotranspiration, resulting in an increase in water vapor in the atmosphere, which falls later as rain; and it is also due to the city's environment, as the Benoue River in Cameroon runs through it. However, among the three localities studied, it appears from these analyses that only in Maroua, the rainfall was illustrated by an absence of break over the study period, represented in Fig. 13, this conclusion corroborates that reported by Bouba et al. (2017), where they had observed that between 1935 and 2011, the rainfall was illustrated by an absence of break both at the inter-annual and inter-monthly scale. However, Fig. 15 indicates a downward trend in rainfall in Maroua, which is similar with the findings of Cheo et al. (2013) and Molua (2006), who indicated that rainfall in Maroua had already decreased between 1957 and 2006; 1960 and 2000. The lack of afforestation in Maroua, as well as the lack of rivers that may pass the towns, such as in Ngaoundere and Garoua, are probably to blame for the drop in reported rainfall. Figures 4, 9 and 14 show rainfall anomalies in Ngaoundere, Garoua and Maroua. The analyses of rainfall indices indicate that dry and wet periods alternate per year, a result that corroborates that reported by Vondou et al. (2021); however, there are years with long wet periods corresponding to six periods in Ngaoundere, three periods in Garoua, and five periods in the case of Maroua; and years with long dry periods also corresponding to two periods in Ngaoundere, one period in Garoua, and two periods in Maroua. Furthermore, these analyses of rainfall indices in the three localities show wet years interspersed with dry years, which is consistent with the conclusion of Nicholson et al. (2018). Figures 6, 11 and 16 show the cumulative monthly rainfall in Ngaoundere, Garoua, and Maroua, respectively. These analyses reveal that cumulative rainfall more than 50 mm occurs in Garoua and Maroua from May to September, and in Ngaoundere from April to October, and this remains in correlation with the results of Djouback (2011). The five months with the greatest potential rainfall in these three research locations are May, June, July, August, and September, with significant rainfall happening only in Ngaoundere from April onwards.

Rather than the findings of Pascal et al. (2022), which demonstrate that the rainy season begins in June and ends in September, our findings reveal that the rainy season begins in April and concludes in October in the three cities analyzed, with an exceptionally early initiation of rainfall in March in Ngaoundere alone. November through March are the dry months in general.

5 Conclusion

This paper provides a description of rainfall trends in the northern part of Cameroon for the period from 1973 to 2020. During this period, rainfall variability is clearly shown, with significant trends of increasing annual rainfall in Ngaoundere and Garoua; and a decreasing trend in rainfall observed in Maroua (Figs. 2, 7 and 12). In the Ngaoundere area, a break in rainfall occurred in 1996 according to the Pettitt test and in 1981 according to the Buishand test; and in the Garoua area a break in rainfall occurred in 1987 according to both tests (Pettitt and Buishand). On the other hand, no rainfall break is observed in the Maroua area. However, August is the month with the highest rainfall recorded in the three regions of Ngaoundere, Garoua and Maroua with an average rainfall of 239 mm, 199 mm and 218 mm respectively. This assessment shows that rainfall remains dynamic from 1973 to 2020 in this part of Cameroon, with an increasing trend in rainfall in Ngaoundere and Garoua, and another decreasing trend in rainfall in Maroua. However, after the last wet period from 2016 to 2019 observed in Garoua, it is reported that a dry year will appear, particularly in 2020, and unlike Maroua where during this same period (2016–2019) there was a dry period, and where it is reported that a wet year will return in 2020; these different changes observed could be seen as a manifestation of a return to normal conditions in the case of Maroua, and a usual alternation of dry years in the Garoua region. Contrary to similar studies conducted by Nicholson et al (2018), where rainfall data were derived from global or default data on long series (from 1889 to 2014), Bouba et al. (2017), on long series (1935 to 2011) and Molua (2006) on long series (1960 to 2000); the present study dates from 1973 to 2020, with an inter-temporal dimension of 48 years due to the updated field data available from ASECNA and CCAA weather stations. The results of this study could help in the predictions or simulations of crop models and also allow the monitoring of the evolution of the climate specifically integrating the rainfall parameter; in order to reduce the risks related to climatic hazards, a credible climate alert system must be implemented on a broad scale to guide farmers. In perspectives, other studies should be put to contribution for the continuation in order to affirm or to deny the arguments of the changes of the wet or dry periods in the next years by widening with more stations.

Declarations

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Figures

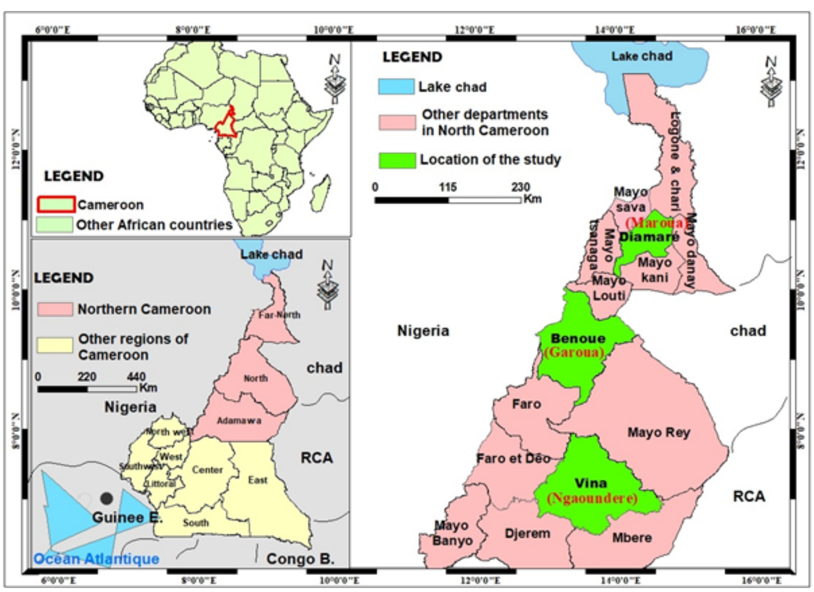


Figure 1

The study area's location (Ngaoundere, Garoua and Maroua)

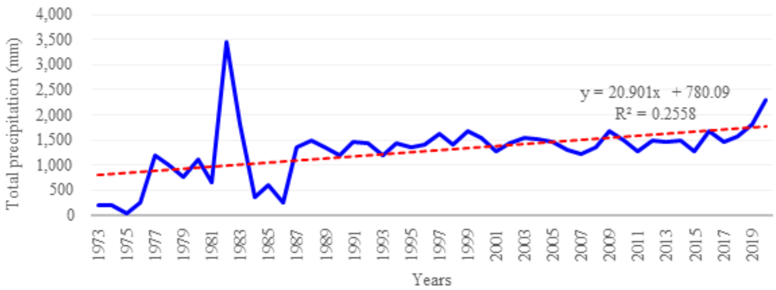


Figure 2

Total recorded rainfall (1973-2020) at the Ngaoundere meteorological station. Dotted line represents the rainfall trend.

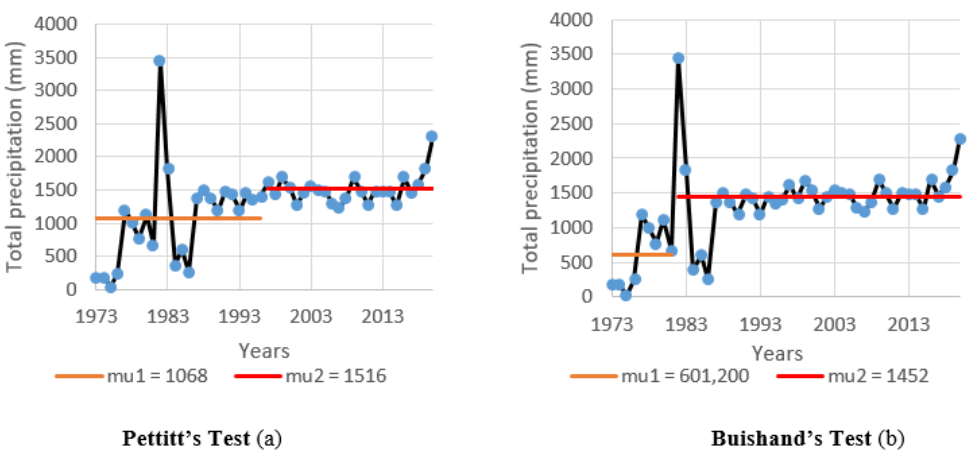


Figure 3

Pettitt (a) and Buishand (b) tests applied to analyze rainfall rupture in Ngaoundere

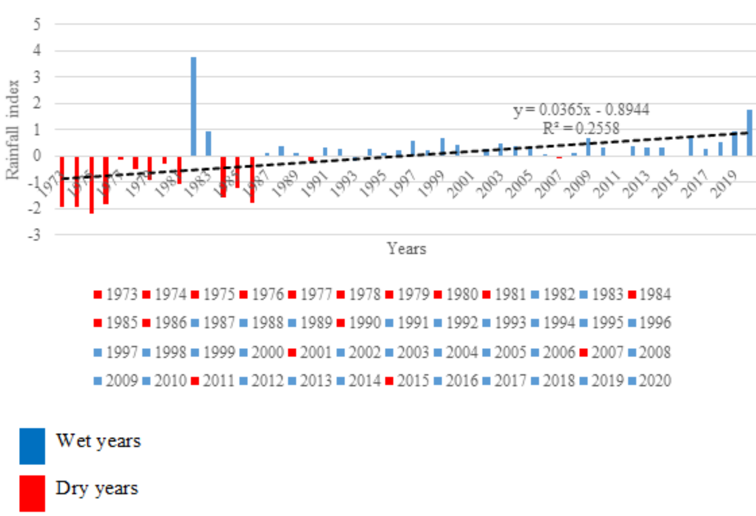


Figure 4

Rainfall anomaly index at Ngaoundere (from 1973 to 2020). Dotted line (black color), the trend

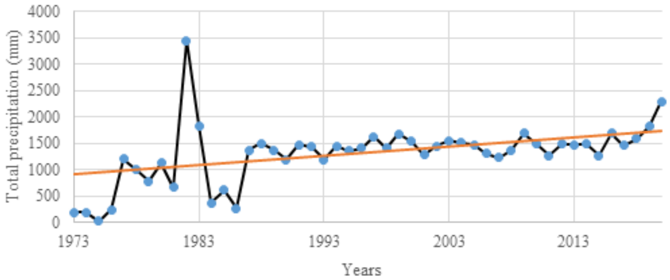


Figure 5

Mann Kendall tests applied to analyze the rainfall trend in Ngaoundere from 1973 to 2020; the orange line represents the Slope of Sen

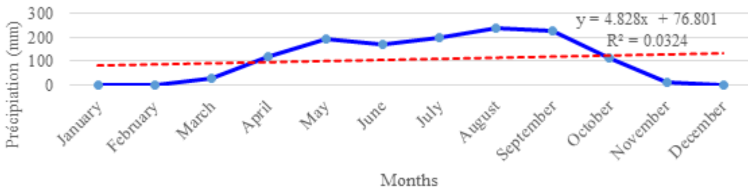


Figure 6

Variation in monthly rainfall in Ngaoundere (1973 to 2020). Dotted line shows the trend.

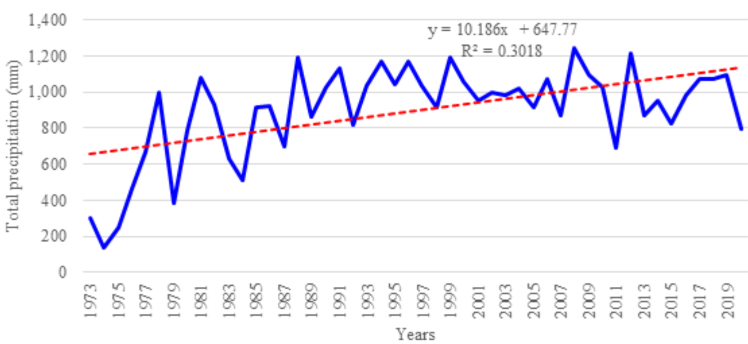
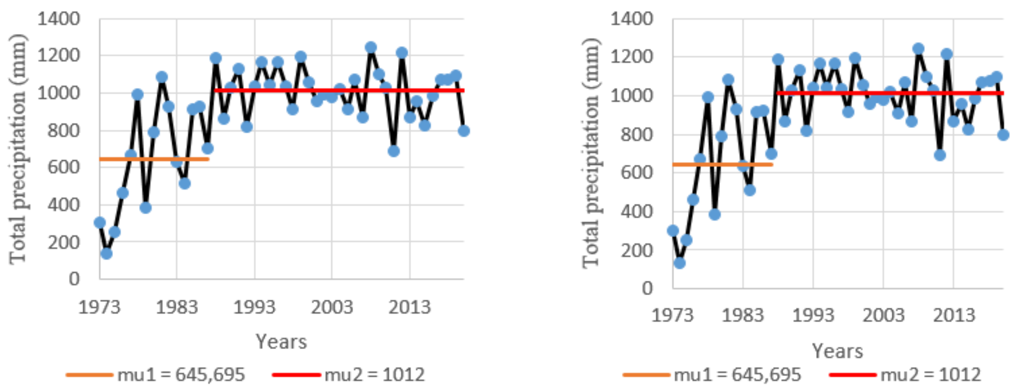


Figure 7

Total recorded rainfall (1973-2020) at the Garoua meteorological station. Dotted line represents the rainfall trend



Pettitt's Test (a) **Buishand' Test** (b)

Figure 8

Pettitt (a) and Buishand (b) tests applied to analyze rainfall rupture in Garoua.

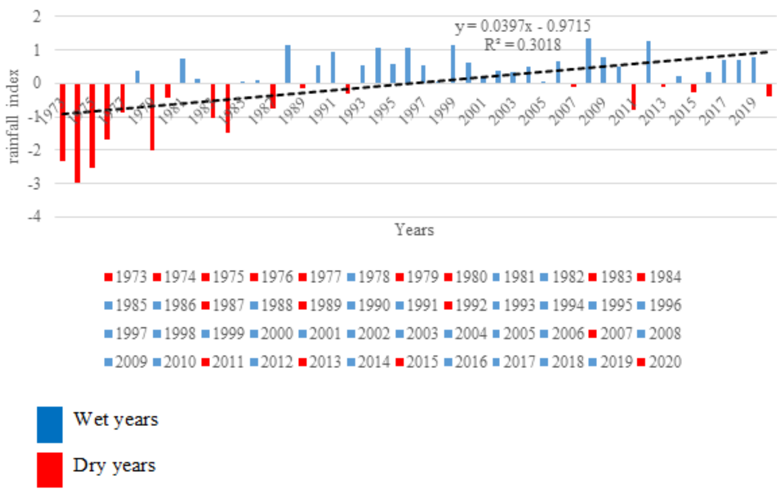


Figure 9

Rainfall anomaly index for Garoua (1973-2020). Dotted line (black color), the trend

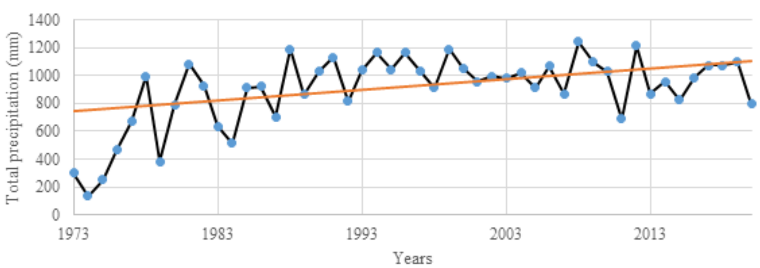


Figure 10

Mann Kendall tests applied to analyze the rainfall trend in Garoua from 1973 to 2020; the orange line represents the Slope of Sen.

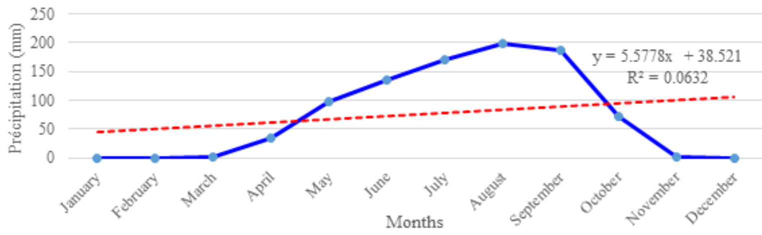


Figure 11

Variation in monthly rainfall in Garoua (1973 to 2020). Dotted line shows the trend

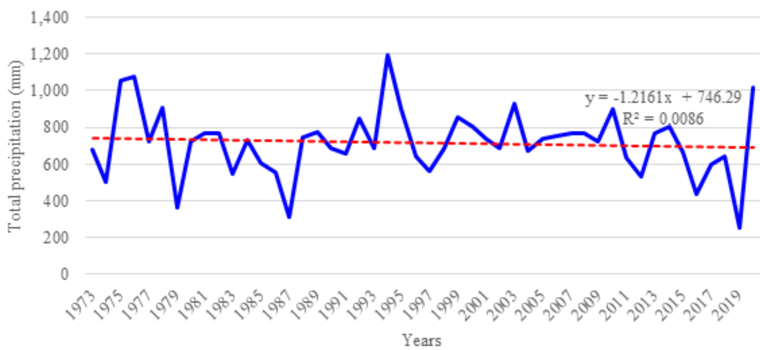


Figure 12

Total recorded rainfall (1973-2020) at the Maroua meteorological station. Dotted line represents the rainfall trend.

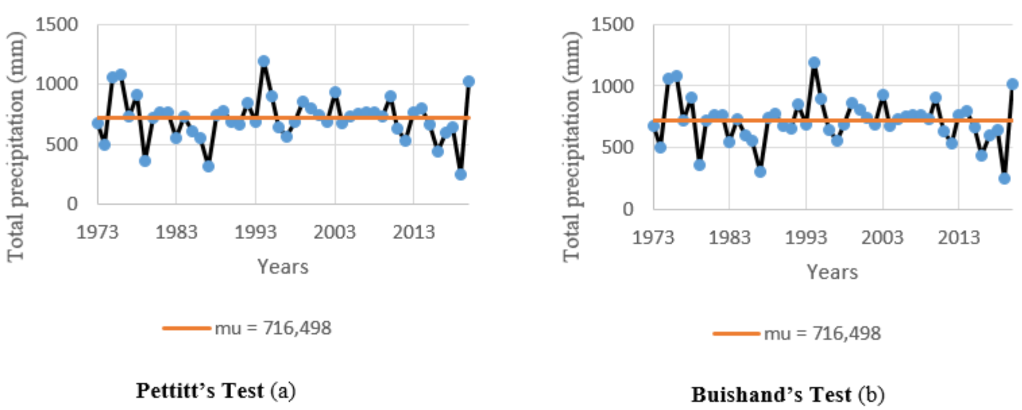


Figure 13

Pettitt (a) and Buishand (b) tests applied to analyze rainfall rupture in Maroua.

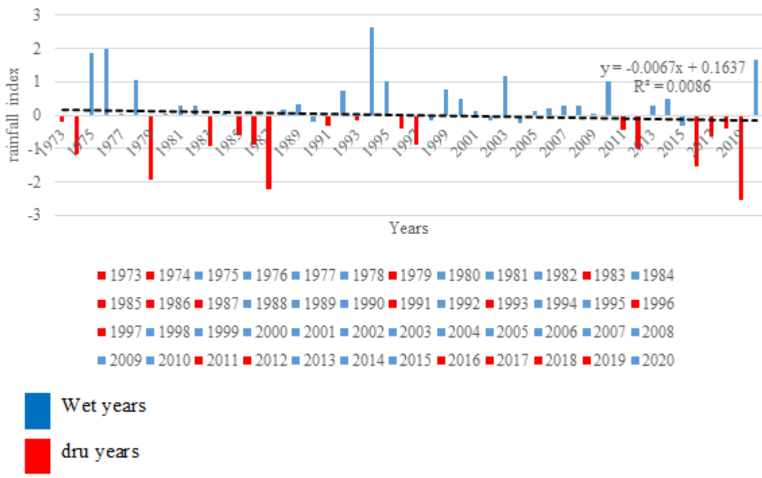


Figure 14

Rainfall anomaly index for Maroua (1973-2020). Dotted line (black color), the trend

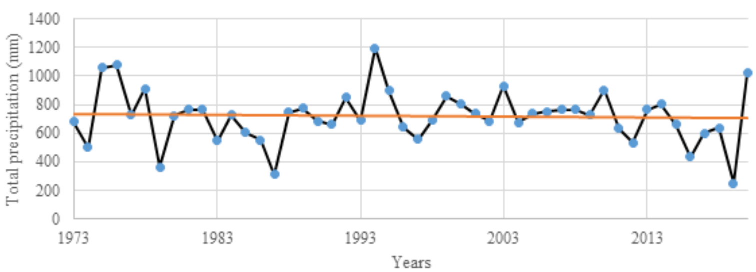


Figure 15

Mann Kendall tests applied to analyze the rainfall trend in Maroua from 1973 to 2020; the orange line represents the slope of Sen.

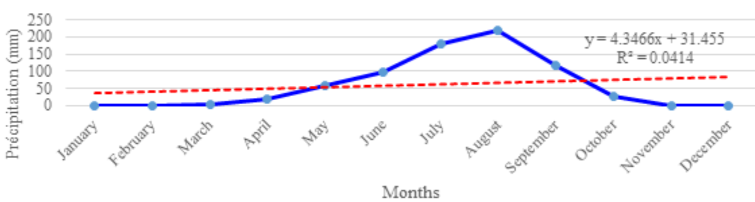


Figure 16

Variation in monthly rainfall in Maroua (1973 to 2020). Dotted line shows the trend.