Analysis of the dynamics of temperature in the northern part of Cameroon

ABSTRACT

The northern part of Cameroon is reported to be vulnerable to climate change and heavily dependent on agriculture. However, few studies have considered the evolution of climatic data that influence agriculture. Existing studies are rarely based on field data. The assessment of precipitation has gained more attention than that of temperature. Few publications have addressed temperature dynamics, and this research contributes to closing that gap by studying the dynamics of three temperature parameters, namely, maximum, minimum and mean temperatures. Data from 1973 to 2020 were collected from weather stations located in three major cities in northern Cameroon: Ngaoundere and Garoua, from the weather stations of the Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA); and Maroua, from the weather station of the Cameroon Civil Aviation Authority (CCAA). The study reveals that in Ngaoundere, the minimum temperature increased by 8.7% between 1987 and 2020 compared to 1973-1986. In Garoua, the mean temperature increased by 2.2% between 2003 and 2020 compared to 1973-2002, the minimum temperature increased by 13.3% between 1985 and 2020 compared to 1973-1984, and the maximum temperature decreased by -8.2%. In Maroua, the mean temperature increased by 3.6% between 2002 and 2020 compared to 1973-2001, and the minimum temperature also increased by 17.8% between 1990 and 2020 compared to 1973-1989; however, the maximum temperature decreased by -6.8% between 1988 and 2020 compared to 1973-1987. The results of this study will be used as the basis for forecasting future agricultural conditions.

Keywords: Northern Cameroon; Climate change; Temperature; Variability; Agricultural conditions.

1. INTRODUCTION

In 1896, the issue of global surface warming was first reported by Arrhenius [1], and according to Olivier et al. [2], Africa could experience an increase in mean temperature on the order of 1. 5 times the global level to 2099; in the northern part of Africa and in West Africa, these temperature increases are reported by Brooke et al. [3] and Philip et al. [4], respectively. Particularly in Central Africa, where temperature projection scenarios would show a gradual warming by the end of the 21st century according to Thierry et al. [5], the authors point out that REMO simulation models show an increase of up to 5 °C and include Cameroon, a country located in Central Africa where the northern regions would certainly be among the most affected by this temperature fluctuation. Peter et al. [6] indicated that climate change could alter climatological and hydrological conditions by bringing considerable changes in temperature and other parameters (rainfall, evapotranspiration), and this could have many effects on cotton production in West and Central Africa, for example. According to Cline [7], beyond certain temperature thresholds, agricultural yields could decrease.

Furthermore, Anderson et al. [8], in their review of the literature, noted that climate-related heat exposure has adverse health effects and that heat waves can lead to catastrophic deaths; they also noted that with climate change, heat waves are expected to be more frequent and severe. This is especially true since the northern part of Cameroon is known to be the hottest area of the country, and observations of temperature changes over the period 1985 to 2006 already showed a considerable increase in average temperature in the northern part of Cameroon compared to the southern part of the country, according to Amélie et al. [9].

Monitoring the dynamics of climatic parameters such as temperatures in a given area would therefore be useful for understanding how the climate works to develop better adapted resilience strategies. The evaluation of the modalities of the possible climatic changes that would affect an area would precede a good knowledge of the functioning of its climate [10] and whose parameter the air temperature would be according to Mitosek [11], among the first four priority variables to be considered in the evaluation of climatic variations.

Given the unavailability of meteorological data in some regions of the country, it appears that scientific publications reporting the analysis of variations in certain climatic parameters would remain insufficient, according to Kaah [12]. However, our study contributes to filling this gap and is spread over the period 1973 to 2020 based on updated field data available at the meteorological stations of ASECNA and CCAA in the study regions.

This paper is presented as follows: Section 2 describes the framework of the study and the methodology. The results are presented in Section 3, which addresses the evolution and variations in temperatures, considering the study areas separately. Section 4 is reserved for discussion, and the conclusion is presented in Section 5.

This research will discuss the temperature variations (mean, minimum and maximum) observed in the different study areas and will provide benefits related to the understanding and knowledge of temperature evolution and variations in agricultural conditions.

2. LOCATION OF THE STUDY AREAS AND METHODOLOGY

2.1 Study areas

This study was conducted in the three main cities of the northern regions (Fig. 1). These areas correspond to the Ngaoundere region located at 7.35°N, 13.56°E latitude and 1114 meters above sea level for an area of 17,196 km²; the Garoua region located at 9.33°N, 13.38°E longitude and 242 meters above sea level for an area of 13,614 km²; and the Maroua region located at 10.45°N, 14.25°E longitude and 423 meters above sea level for an area of 4,665 km².

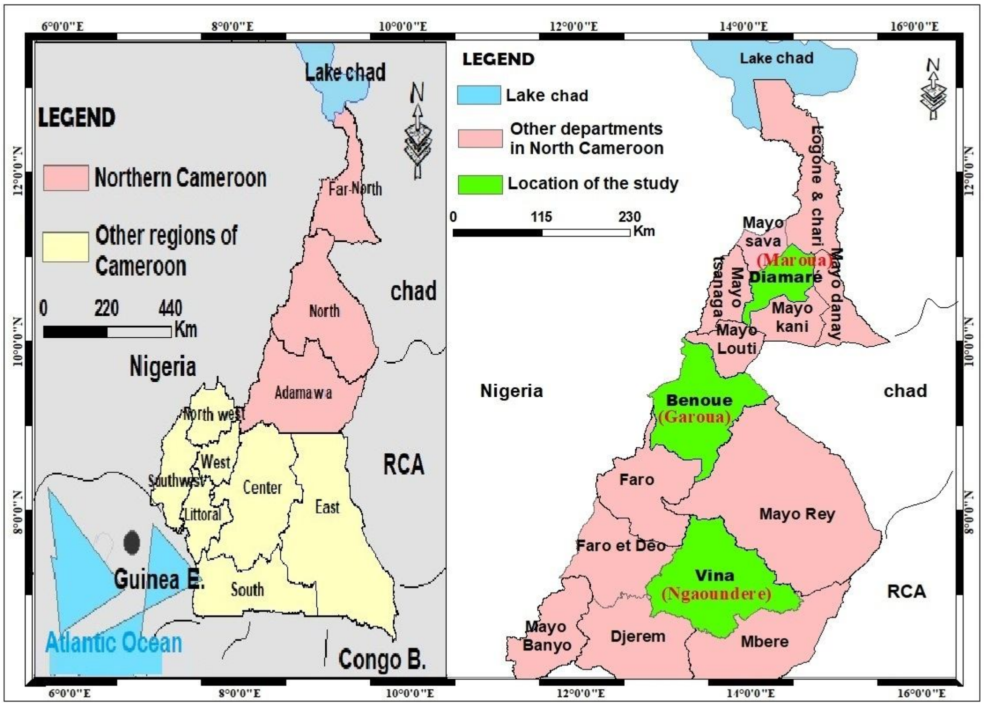

Fig. 1. Location of the studied areas

2.2 Methodology

2.2.1 Data collection

The temperature data collected are from the Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA) weather stations in Ngaoundere and Garoua, while the data for Maroua are from the Cameroon Civil Aviation Authority (CCAA). The observation interval is from 1973 to 2020, or forty-eight years (48 years); see Table 1 below.

Table 1. Observation posts

Weather Stations	Latitude	Longitude	Altitude	Observation period
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

Annual temperature averages were calculated for each station and for the three variables studied:

- Average temperatures: representing the average of the sum of the minimum and maximum temperatures over the observation period.
- Maximum temperatures: representing the highest temperatures recorded during the observation period.
- Minimum temperatures: representing the lowest temperatures recorded during the observation period

The mean, maximum and minimum temperatures (monthly and annual) are obtained from the following equations:

$$\begin{cases} \text{Tm} = \Sigma(\text{Tx})/\text{Nb} \\ \quad\text{and} \\ \text{Ta} = \Sigma(\text{Tx})/\text{Na} \end{cases} \qquad (1)$$

where:

Tm = average monthly temperature (°C);

Ta = average annual temperature (°C);

Tx = average monthly or annual temperature collected at the weather stations (°C);

Nb = total number of months;

Na = total number of years.

2.2.2 Statistical tests

The analysis was based on statistical tools such as SPSS Statistics version 20 and XLSTAT. The tests proposed by Pettitt, Buishand, Mann-Kendall and *Sen's slope* were used.

2.2.2.1 Pettitt's test

It is a nonparametric test used to detect a change point in climate series with continuous data [13]. The independent random variables are X1, X2... XN. The sequence is assumed to contain a breakpoint at τ if the Xt for t = 1... τ have a common distribution F1(X), and the Xt for t = τ + 1… N have a common distribution F2(X), different from F1(X) [14].

H0 is the null hypothesis of "no break", and H1 is the alternative hypothesis of "break".

$$\begin{cases} \text{H0}: \tau = \text{N} \\ \quad\text{and} \\ \text{H1}: 1 \le \tau < N \end{cases} \qquad (2)$$

$$ifD_{ij} = sign\left(X_i - X_j\right) \qquad (3)$$

$$sign\,(X) = 1\ if\ X > 0\,; 0\ ifX = 0\ and - 1\ if\ X < 0, \qquad (4)$$

Then, the variable

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=1+1}^{N} D_{ij} \qquad (5)$$

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=1+1}^{N} sign\left(x_i - x_j\right) \qquad (6)$$

$$K_N = \max_{1\le t<N}\left(\left|U_{t,N}\right|\right) \qquad (7)$$

$$Prob(K_N > K) \approx 2\exp\left\{-\frac{6{K_N}^2}{N^3+N^2}\right\} \qquad (8)$$

2.2.2.2 Buishand's test

Buishand's test is a parametric test whose statistic is said to be derived from an original formulation given by Gardner, according to Lang et al. [15]; this statistic is written as follows:

$$G = \sum_{k=1}^{p-1} P_k \left\{\frac{S_k}{\sigma_x}\right\}^2 \qquad (9)$$

$$S_k = \sum_{i=1}^{t} \left(\overline{X_\iota} - \overline{X}\right) \qquad (10)$$

$$\text{U} = \frac{\sum_{i=1}^{N-1}\left(\frac{S_k}{D_x}\right)^2}{N(N+1)} \qquad (11)$$

$$D^2{}_x = \sum_{i=1}^{N} \left(\overline{X_\iota} - \overline{X}\right)^2 / \text{N} \qquad (12)$$

2.2.2.3 Mann-Kendall Test

It is a nonparametric test commonly used to identify monotonic trends in environmental, climatic or hydrological data sets [13]. The null hypothesis (H0) states that the data are equally distributed among populations with independent realizations. A monotonic trend in the data is the alternative hypothesis (Ha). Yue et al. [16] state that with the nonparametric Mann-Kendall test, trends are only considered representative when they are statistically significant at the 0.05 or 5% level. The Mann-Kendall test is calculated as follows [17]:

$$S = \sum_{k=1}^{N-1} \sum_{j=k+1}^{N} sign\left(X_j - X_k\right)$$

(13)

$$sign\,(x) = \begin{cases} 1 \text{ if x} > 0 \\ 0 \quad if\ x = 0 \\ -1 \text{ if x} < 0 \end{cases} \qquad (14)$$

$$\begin{cases} sign\left(X_j - X_k\right) = 1, \quad \text{if}\left(X_j - X_k\right) > 0 \\ sign\left(X_j - X_k\right) = 0, \ \text{if}\left(X_j - X_k\right) = 0 \\ sign\left(X_j - X_k\right) = -1, \ \text{if}\left(X_j - X_k\right) < 0 \end{cases} \qquad (15)$$

If E(S) = 0, the variance Var (S) is:

$$Var(S) = \left\{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j - 1)(2\,t_j + 5)\right\}/18 \qquad (16)$$

If the sample contains ten or more data points, the distribution of the test statistic Z below will be approximated by a center-reduced Gaussian.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var\ (S)}}, & \text{if S > 0} \\ 0, & \text{if S = 0} \\ \frac{S+1}{\sqrt{Var\ (S)}}, & \text{if S < 0} \end{cases} \qquad (17)$$

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

$$\tau = \frac{S}{D} \qquad (18)$$

$$D = [\tfrac{1}{2}n(n-1) - \tfrac{1}{2}\sum_{j=1}^{p} t_j(\ t_j - 1)]^{\frac{1}{2}}\ [\tfrac{1}{2}n(n-1)]^{\frac{1}{2}} \qquad (19)$$

2.2.2.4 *Sen's slope*

Sen's slope is estimated by Sen's method [18]; 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, for which X_{ij} is an estimate of the slope calculated as follows:

$$X_{ij} = \left\{\frac{Y_j - Y_i}{t_j - t_i}\right\},\ (i, j) \in S \qquad (20)$$

According to Fawaz et al. [19], the Sen Slope estimator proves to be a powerful tool for developing linear relationships; a positive Sen Slope indicates an upward trend, while a negative Sen Slope suggests a downward trend.

2.2.2.5 *Temperature index analysis*

Temperature anomalies are determined in the same way as precipitation anomalies, and a less warm year occurs when the index constantly shows a negative value of -1.0 or below and terminates when the index turns positive, becoming a warm year [20]. The anomalies of the different parameters are calculated by the formula: $IP = \frac{X_i - \bar{X}}{\sigma(x)}$

(21)

where IP is the centered reduced anomaly for year i; X_i is the value of the variable (temperature); $\bar{X}$ is the mean of the series; and $\sigma(x)$ is the standard deviation of the series. Analysis of the standard deviation (an indicator of climate variability) allows us to assess the dispersion of values around the mean. This standard deviation is determined by the following formula:

$$\sigma(x) = \sqrt{v} \qquad (22)$$

where σ(x) and v represent the standard deviation and variance, respectively. From the standard deviation, the monthly and interannual thermometric reduced center anomalies are calculated.

2.2.3 Analysis of data homogeneity

We use the Pettitt test and the Buishand test to test for homogeneity in the data. The technique is to divide our dataset (1973-2020) into two equal-sized samples (1973-1996 and 1997-2020) and then try to compare the two means of each sample to see if there is any significant variation between the two samples. It is very interesting to first perform a comparison of variances test before performing a comparison of means test (Fisher test). Student's t test was used to compare the means if Fisher's test showed that the variances were equal; if the variances were not equal, Welch's test was used to compare the means. In conclusion, the results of these tests indicate that our data are more or less strongly homogeneous because the means of the two samples are equal. Furthermore, to check the homogeneity of the whole sample, we use two tests: the Pettitt test and the Buishand test (1973 to 2020).

3. RESULTS

Following the statistical treatment of these series, it appears that the data arranged in the different study areas are homogeneous in the majority of cases.

3.1 Evolution and variation of temperatures in Ngaoundere

Fig. 2 below represents the evolution of temperatures in Ngaoundere from 1973 to 2020. The analysis shows that temperatures have fluctuated slightly over these 48 years; the trends are positive since the linear regression analysis shows an annual increase in temperatures. Note that $R^2 = 0.0107$ for maximum temperature and $R^2 = 0.0013$ for average temperature generally reflect variation with year; however, $R^2 = 0.0531$ for minimum temperature reflects significant variation with years; thus, we see that the minimum temperature has increased more than the other two parameters (maximum and mean temperatures). We also see that the highest maximum temperature value was recorded in 2016, with a value of 33 °C, and then it decreased by 30 °C in 2020. The highest mean temperature was 23 °C, which was last recorded in 1998, and then it decreased slightly to 22 °C in 2020. The highest minimum temperature was 16 °C, and the last was recorded in 2020; the lowest recorded minimum temperature was 11 °C, and the last was recorded in 1983.

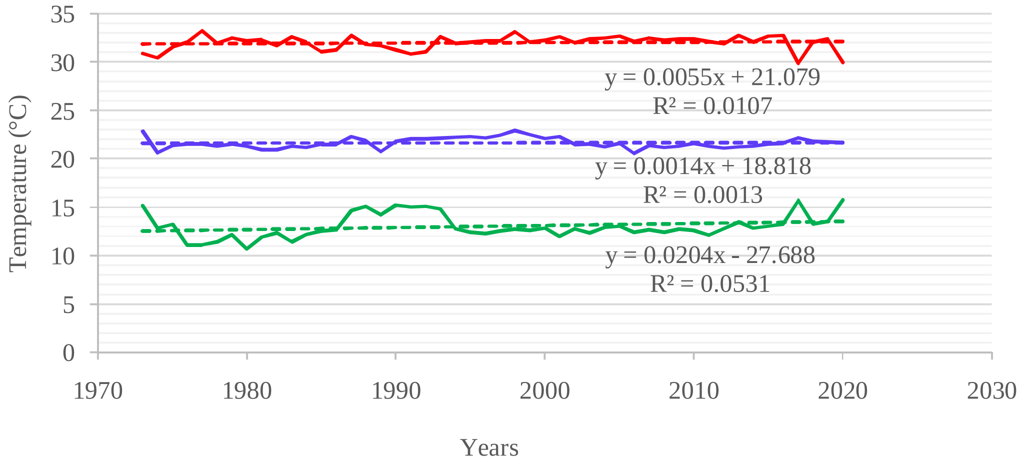

Fig. 2. Annual average annual maximum, mean and minimum temperatures (in red, blue and green, respectively) at the Ngaoundere weather station.

3.1.1 Anomalies in mean temperature at Ngaoundere

As a result of these analyses, the mean temperatures at Ngaoundere over the period 1973-2020 (48 years) show 22 hot years and 26 less hot years (Fig. 3). The hot years show two periods from 1990 to 2001 and from 2017 to 2020 and three less hot periods from 1978 to 1986, from 2002 to 2004 and from 2006 to 2016. There are also hot years and less hot years in the above periods: this is the case for

1973, 1974, 1975, 1976, 1977, and 2005. The linear regression analysis shows a very slight increase in mean temperatures from 1973 to 2020. Note that the R^2 value = 0.0013 shows little variation in mean temperatures between years.

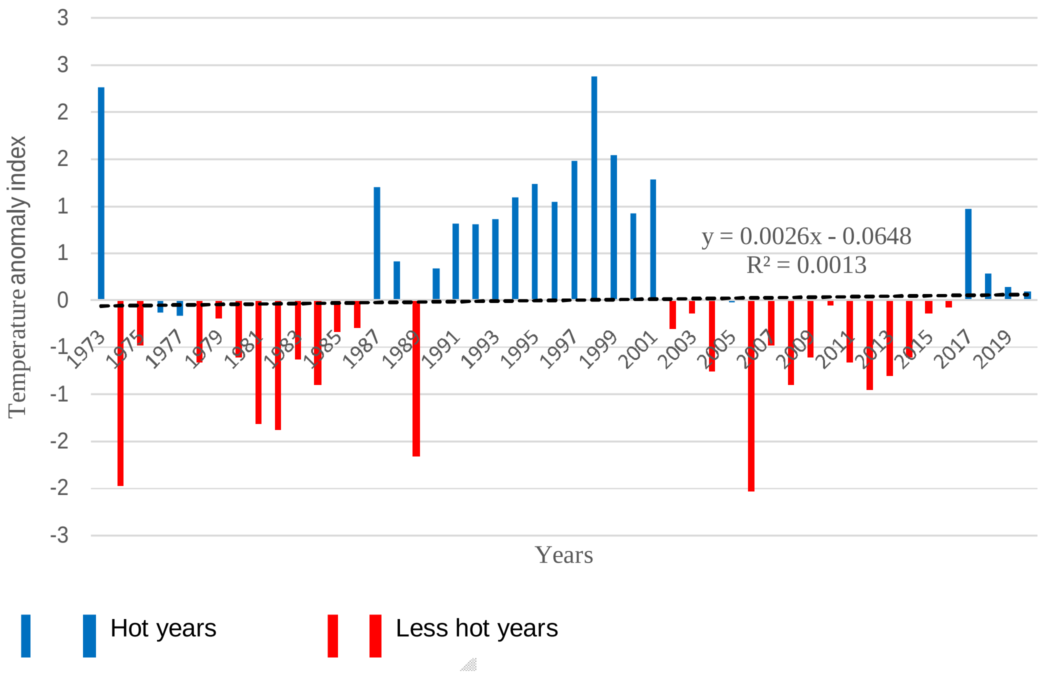

Fig. 3. Mean temperature anomaly index in Ngaoundere.

3.1.2 Trend of temperature data in Ngaoundere

After performing the trend test of the mean and maximum temperature series in Ngaoundere of the parent sample taken between 1973 and 2020, i.e., 48 years, it appears that there is no trend in these two series and therefore no variation since the p-value of the trend tests of the mean and maximum temperature data (P-value of the mean temperature test = 0. 4825 > 0.05 (5%); the P-value of the maximum temperature test = 0.0698 > 0.05 (5%)) calculated is above the significance level of the alpha=0.05 threshold, and the null hypothesis H0 "There is no trend in the series" cannot be rejected. On the other hand, increasing trends are observed in the minimum temperature series, and therefore, a significant variation is observed for this variable. Since the p-value of the minimum temperature trend test ((P-value of the minimum temperature test = 0.0065 < 0.05 (5%)) calculated is less than the significance level alpha=0.05, we must reject the null hypothesis H0 and retain the alternative hypothesis Ha. "There are trends in the series"; (Fig. 4 a, b, c).

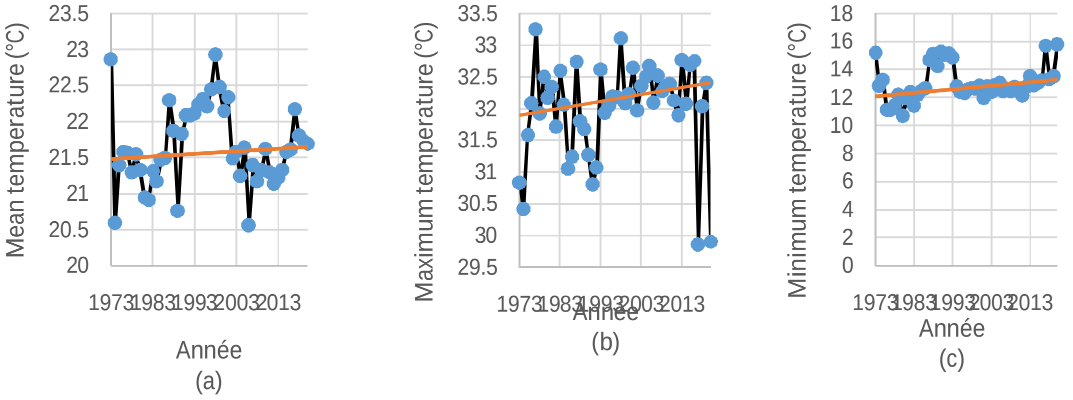

Fig. 4. Mann-Kendall tests were applied to analyze the trend of mean temperature (a), maximum temperature (b) and minimum temperature (c) in Ngaoundere.

3.1.3 Monthly temperature variation in Ngaoundere

Fig. 5 below presents the monthly temperature variability (maximum, mean and minimum) at Ngaoundere over the period 1973 to 2020 (48 years), which is necessary to distinguish the hottest months from the coldest months; from this analysis, it appears that the climate in Ngaoundere is a humid tropical climate with three seasons: a short very hot season that runs from February to April (3 months), a long mild season that runs from May to October (6 months), and a short very cold season that runs from November to January (3 months); however, March remains the hottest month, with a maximum recorded temperature of 35 °C; December and January are the two coldest months, with a minimum recorded temperature of 8 °C.

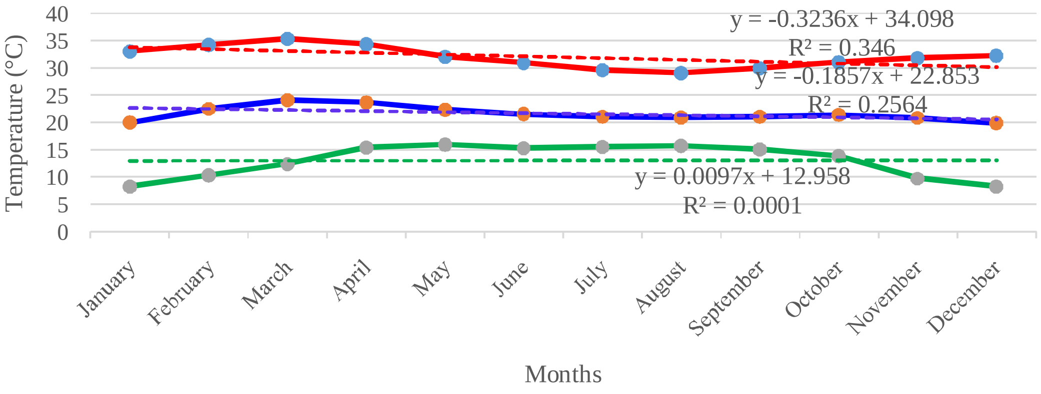

Fig. 5. Monthly variation in maximum, mean and minimum temperatures (in red, blue and green, respectively) at the Ngaoundere weather station.

3.2 Evolution and variation of temperatures in Garoua

Fig. 6 below shows the evolution of temperatures in Garoua from 1973 to 2020. The analysis shows that temperatures fluctuate slightly over these 48 years; the trends are positive, as the linear regression analysis shows an interannual increase in temperatures. It should be noted that the value R^2 = 0.1016 for the maximum temperature and R^2 = 0.215 for the mean temperature generally show a variation according to year; the value R^2 = 0.4659 for the minimum temperature reflects a significant variation according to year; thus, we note that the minimum temperature increased more than the two other parameters (maximum and mean temperatures) and that the maximum temperature is decreasing. We also noticed that the value of the highest maximum temperature was 39 °C, whose last date of recording was in 1980, and there was subsequently a large drop of 36 °C in 2020. The highest mean temperature was 29 °C, with the last date of recording in 2020, which increased slightly since 1974 and 1989 when 27 °C was recorded. The highest minimum temperature was 23 °C, the last was recorded in 2020, the lowest recorded minimum temperature was 17 °C, and the last was recorded in 1977.

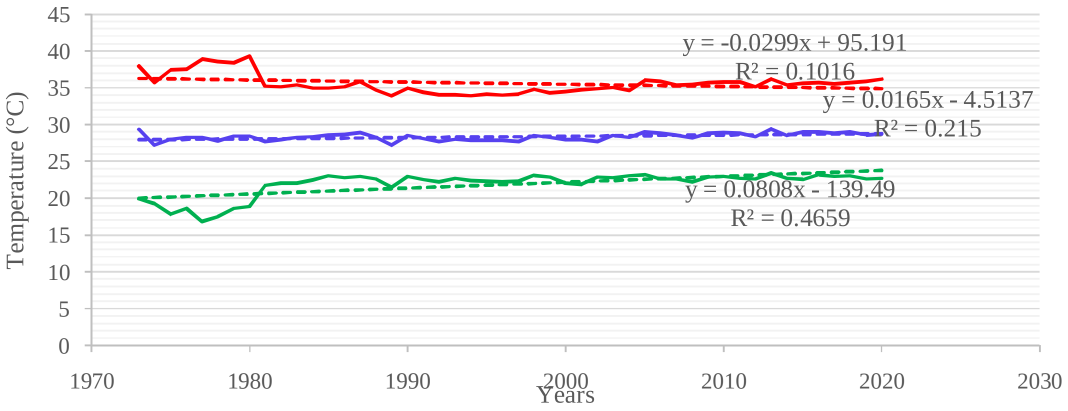

Fig. 6. Annual average annual maximum, mean and minimum temperatures (in red, blue and green, respectively) at the Garoua weather station.

3.2.1 Anomalies in mean temperature in Garoua

Based on the analyses, the mean temperatures in Garoua over the period 1973-2020 (48 years) show 24 hot years and 24 less hot years (Fig. 7). The hot years include 3 periods from 1984 to 1987, 2005 to 2008 and 2009 to 2020 and 4 less hot year periods from 1974 to 1978, 1981 to 1983, 1991 to 1997 and 1999 to 2002. We also note the presence of hot years and less hot years in the above periods: this is the case for 1973, 1979, 1980, 1998, 2003, 2004 and 2008. The linear regression analysis shows an interannual increase in mean temperatures from 1973 to 2020. Note that the R^2 value = 0.215 shows a significant variation in mean temperatures between years.

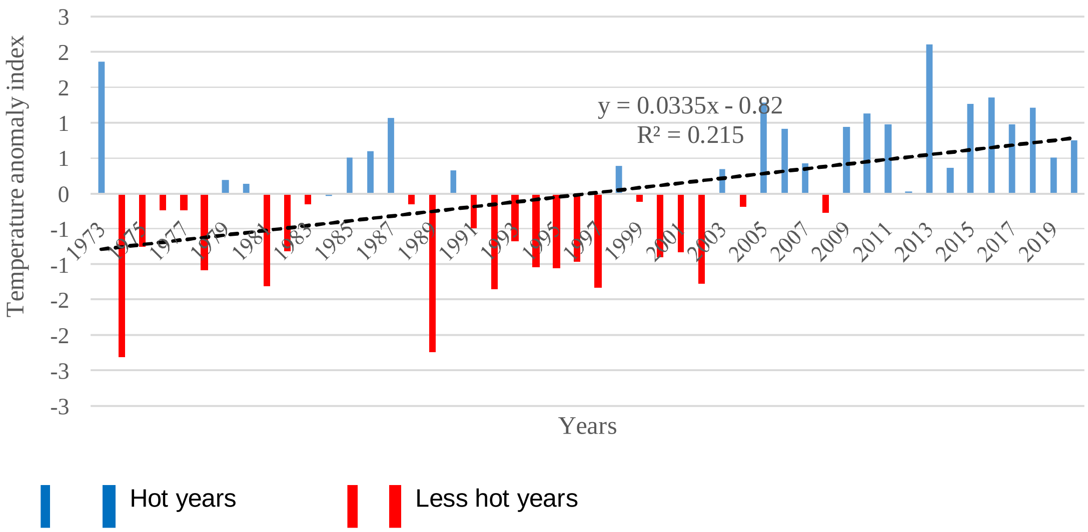

Fig. 7. Mean temperature anomaly index in Garoua.

3.2.2 Trend of temperature data in Garoua

After performing the trend test on the series of maximum temperatures in Garoua from the parent sample taken between 1973 and 2020, i.e., 48 years, it appears that there is no trend in this series and therefore no variation (Fig. 8b) because, given that the P-value of the test of trends in maximum temperatures ((P-value of the test of maximum temperatures = 0.8519 > 0.05 (5%)) calculated is higher than the level of significance threshold alpha=0.05, we cannot reject the null hypothesis H0 "There is no trend in the series".

On the other hand, increasing trends are observed in the series of mean and minimum temperatures; therefore, significant variations are observed for these two variables. Because, given that the p-value of the tests of tendencies of the mean, minimum temperatures (P-value of the test of mean temperatures = 0.0006 < 0.05 (5%), (Fig. 8a); P-value of the test of minimum temperatures= 0.0000033 < 0,05 (5%)) calculated is lower than the level of significance alpha=0,05, one must reject the null hypothesis (H0) and retain the alternative hypothesis (Ha). "There are trends in the series" (Fig. 8 c).

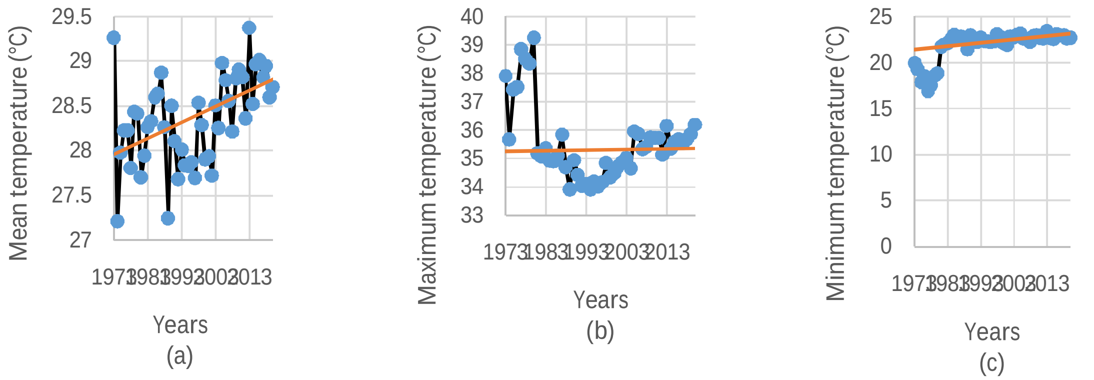

Fig 8. Mann-Kendall tests were applied to analyze the trends of mean temperature (a), maximum temperature (b) and minimum temperature (c) in Garoua.

3.2.3 Monthly temperature variation in Garoua

Fig. 9 below presents the monthly temperature variability (maximum, mean and minimum) in Garoua over the period 1973 to 2020 (48 years), which is necessary to distinguish between the hottest and coldest months; the climate in Garoua is a dry tropical climate with three seasons: a short very hot season that runs from February to April (3 months), a long mild season that runs from May to October (6 months), and a short very cold season running from November to January (3 months); however, March and April remain the hottest months, with a maximum rerecorded temperature of 41 °C; December and January are the two coldest months, with a minimum recorded temperature of 17 °C.

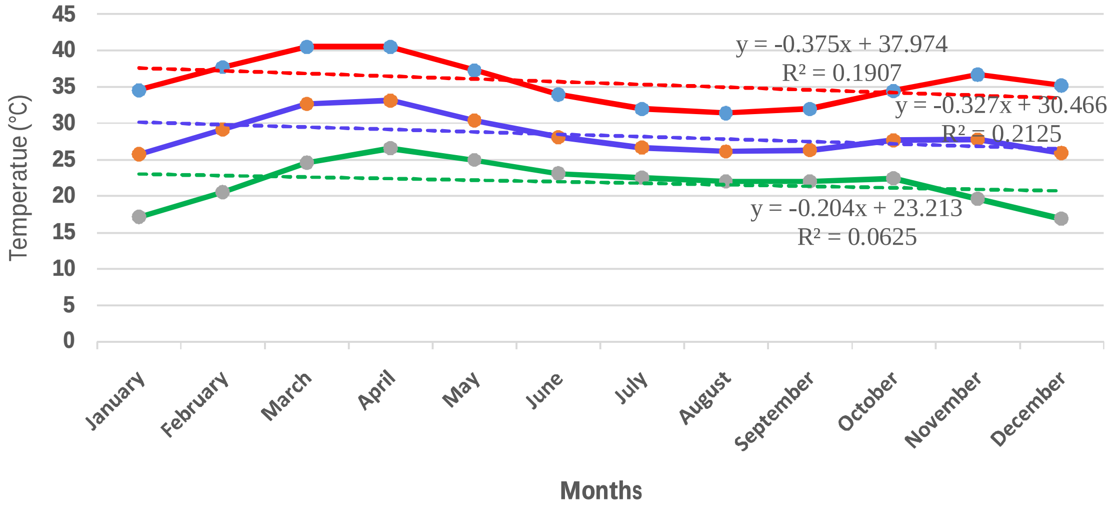

Fig. 9. Monthly variation in maximum, mean and minimum temperatures (in red, blue and green, respectively) at the Garoua weather station.

3.3 Evolution and variation of temperatures in Maroua

Fig. 10 below shows the evolution of temperatures in Maroua from 1973 to 2020. It follows from this analysis that temperatures over these 48 years have undergone significant fluctuations. It should be noted that the R^2 = 0.3081 value for the maximum temperature shows a variation depending on the years, with a negative trend; however, the R^2 = 0.3806 value for the mean temperature and R^2 = 0.6632 for the minimum temperature reflect a significant variation depending on the years; therefore, we note that the mean and minimum temperatures have increased while the maximum temperature is decreasing. We also noticed that the highest maximum temperature value was 39 °C, which was last recorded in 1979; there was then a large drop in this value, as 34 °C was recorded in 1989 and 35 °C in 2020. The highest mean temperature was 32°C, and the last was recorded in 2020, which is an increase of 5°C compared to the 27°C recorded in 1989. The highest minimum temperature was 25 °C, with the last recorded in 2020; the lowest minimum temperature recorded was 16 °C, with the last recorded in 1978.

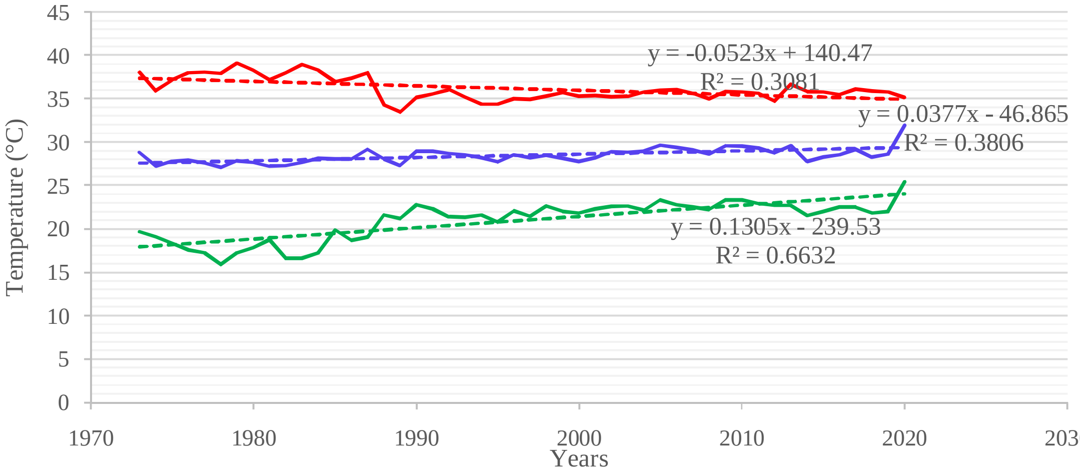

Fig. 10. Annual average annual maximum, mean and minimum temperatures (in red, blue and green, respectively) at the Maroua weather station.

3.3.1 Anomalies in mean temperature in Maroua

The analyses show that the mean temperatures in Maroua over the period 1973-2020 (48 years) show 22 hot years and 26 less hot years (Fig. 11). The less hot years have 3 periods from 1974 to 1986, 1997 to 2001 and 2014 to 2016 and 2 hot years periods from 1990 to 1993, 2002 to 2013 and 2002 to 2004.

We also note the presence of hot and not hot years in the above periods: this is the case for 1973, 1987, 1994, 1995, 2017, 2018, 2019 and 2020. The linear regression analysis shows an interannual increase in mean temperatures from 1973 to 2020. Note that the R^2 value = 0.3806 shows a variation in mean temperatures between years.

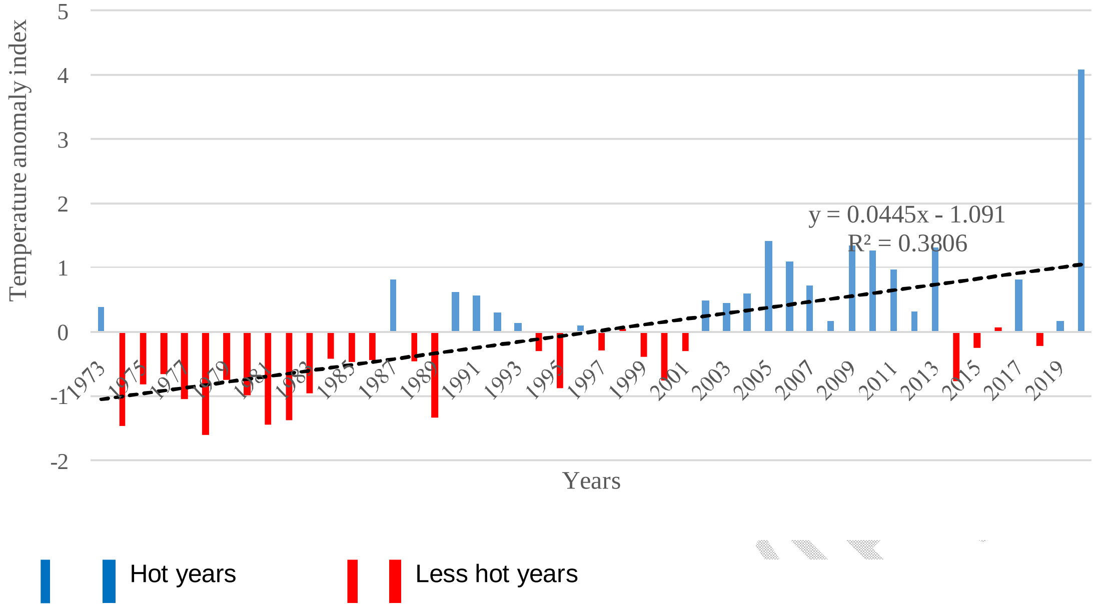

Fig. 11. Mean temperature anomaly index at Maroua.

3.3.2 Trend of temperature data in Maroua

After having carried out the trend test of the temperature series in Maroua of the parent sample taken between 1973 and 2020, i.e. 48 years, increasing trends are observed in the series of mean and minimum temperatures; therefore, significant variations are observed for these two variables (Fig. 12 a, c); however, a significant decreasing trend is observed in the maximum temperatures (Fig. 12 b). The computed P-value of the tests of trends in mean, minimum and maximum temperatures ((P-value of the test of mean temperatures = 0.0000 < 0.05 (5%); P-value of the test of minimum temperatures= 0.0000 < 0.05 (5%); P-value of the test of maximum temperatures = 0.0152 < 0.05 (5%)) is lower than the level of significance alpha=0.05, and we must reject the null hypothesis H0 and retain the alternative hypothesis (Ha). "There are trends in the series".

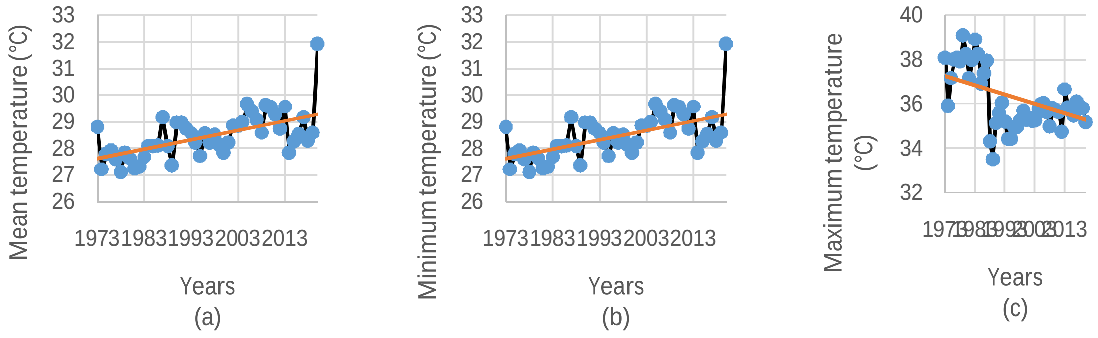

Fig. 12. Mann-Kendall tests were applied to analyze the trend of mean temperature (a), minimum temperature (b) and maximum temperature (c) in Maroua.

3.3.3 Monthly temperature variation in Maroua

Fig. 13 below presents the monthly temperature variability (maximum, mean and minimum) in Maroua over the period 1973 to 2020 (48 years), which is necessary to distinguish between the hottest and coldest months; the climate in Maroua is a dry tropical climate of the Sahelian type with three seasons: a long very hot season that runs from February to May (4 months), a short, mild season that runs from June to October (5 months), and a short cold season running from November to January (3 months); however, April is the hottest month, with a maximum recorded temperature of 41 °C; December and January are the two coldest months, with a minimum recorded temperature of 16 °C.

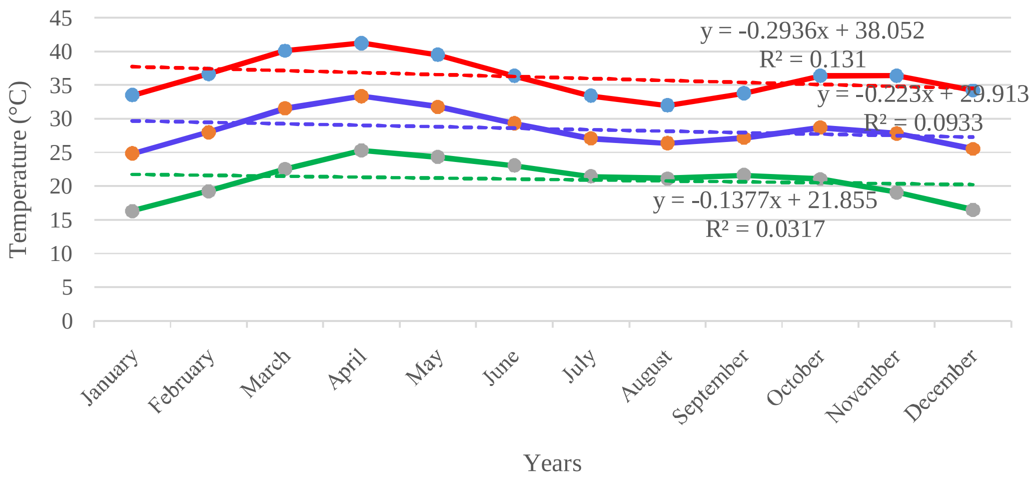

Fig. 13. Monthly variation in maximum, mean and minimum temperatures (in red, blue and green, respectively) at the Maroua weather station.

4. DISCUSSION

Figs. 2, 6 and 10 show the evolution of maximum, minimum and mean temperatures in Ngaoundere, Garoua and Maroua, respectively. The analysis of the results of the statistical tests illustrated in Fig. 4 a b c; Fig. 8 a b c and Fig. 12 a b c shows that the temperature dynamics in these localities were largely unstable, with increases in the minimum temperature observed in Ngaoundere and Garoua. The mean temperature also increased in Ngaoundere, Garoua and Maroua (Fig. 8; Fig. 4 a Fig. 12 a). These analyses corroborate those reported by Molua et al. [21], who reported that temperatures in Cameroon have been increasing since 1930 according to studies by Ayonghe in 2001 and that this net rate of increase was already 0.95 °C between 1930 and 1995.

The increase in temperature in Cameroon in general would be due, on the one hand, to the modification of the composition of the atmosphere by the accumulation of greenhouse gases from bushfires that bring CO2 into the atmosphere and from deforestation, resulting in the loss of an important carbon sink; on the other hand, this increase in temperature would also be due to the large number of air conditioners, for example, as well as the increase in infrastructure, through the urban heat island effect. According to Molua et al. [21], northern Cameroon faces a severe lack of reforestation.

This analysis agrees with that reported by Bring et al. [22], who reported a severe lack of reforestation in these localities. Mubarak et al. [23] also reported that an increase in the number of air conditioners indirectly increases the amount of CO2 in the atmosphere, particularly refrigerators and air conditioners that operate with several types of refrigerants, including chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). The authors point out that leakage of these fluids can occur several times during the life cycle of an air conditioner for a variety of reasons; these substances released in this way would have adverse effects on the environment, as they deplete the ozone layer and act as potent greenhouse gases (warming of air temperature) up to 1000 times more potent than CO2; Thierry et al. [5] show that all temperature projections made result in a gradual warming by the end of the 21st century; for the future period (2070-2095), the temperature is expected to increase under the three scenarios described (RCP2.6, RCP4.5 and RCP8.5); the authors indicate that REMO simulation models show an increase of up to 5 °C over Central Africa, depending on the RCP scenarios.

However, our study shows a decrease in minimum temperature at Maroua (Fig. 12 c), and this analysis is consistent with that reported by Cheo et al. [24]. Fig. 3, Fig. 7 and Fig. 11 show the mean temperature anomalies in Ngaoundere, Garoua and Maroua, calculated in the same way as the rainfall anomalies [20]. These variables were used to characterize the hot and not hot periods, and the magnitude of this variability then varies according to the station concerned.

The analyses of the temperature indices indicate that the hot and not hot periods alternate each year. This result corroborates those reported by Molua [20] and Nicholson et al. [25]; however, there are years with long hot periods corresponding to two periods in Ngaoundere, three periods in Garoua, and two periods in the case of Maroua and years with long less hot periods corresponding to three periods in Ngaoundere, four periods in Garoua, and three periods in the case of Maroua. Furthermore, these analyses of temperature anomaly indices in the three localities show warm years interspersed with less hot years, and this analysis is consistent with the conclusion of Nicholson et al. [25]. Fig. 5, Fig. 9 and Fig. 13 illustrate the monthly temperature variations (mean, maximum and minimum, respectively) in Ngaoundere, Garoua and Maroua. It appears from these analyses that the maximum temperatures in Garoua and Maroua are 41 °C and 35 °C in Ngaoundere; these analyses are in agreement with the results of Claessens et al. [26]. Concerning March as the base month (hottest month) for the calculation of the heat balance of the air conditioners, however, contrary to the value of 39.8 °C used in Garoua by the authors, our study shows a temperature of 41 °C for this locality. This temperature increase of +1.2 °C therefore reflects the temperature dynamics observed in this locality. The least warm periods are December and January; however, the best period for crops is from May to October, i.e., six months.

CONCLUSION

This paper analyzes the temperature dynamics in the northern part of Cameroon over the period 1973-2020. During this period, temperature variability is reported, with significant trends towards increasing mean and minimum temperatures in the three localities of Ngaoundere, Garoua and Maroua. However, March is recorded at all three sites as the hottest month, with an extension of the heat into April in Garoua and Maroua. The results of this study could help in predictions or simulations of crop models and allow the monitoring of climate change by specifically integrating temperature parameters to reduce risks related to climate hazards. In the future, other studies should be used for the analysis of heat indices, useful for human health prevention, by associating the relative humidity parameter. Finally, this analysis of temperatures (mean, maximum and minimum) in the capitals of the northern regions of Cameroon has made it possible to highlight the upward trend in minimum and mean temperatures in Ngaoundere and Garoua and to demonstrate the downward trend in maximum temperature only in Maroua over the period 1973-2020. Understanding the evolution and variations in temperatures in the localities of northern Cameroon will remain an important step to consider to better integrate the process of adaptation to the negative effects of climate change, particularly in the agricultural sectors in Cameroon.

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