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Comparative analysis of the evolution of rainfall in Maiduguri, Nigeria and Ndjamena in Chad, two towns located at the same latitude in the African inter-tropical region

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Abstract
Maiduguri and Ndjamena are two cities on the same latitude. Their latitudinal rapprochement does not confer the same rainfall, since both cities have different amounts of rainfall. At the annual level, a constant decrease in rainfall is observed in the two cities over the period of the study. The observed decline is confirmed by the negative trends of equations. Rainfall break points are at different periods respectively in 1963 for Maiduguri, and 1962 for Ndjamena.
The cumulative changes in precipitation for both regions shows an increase phase, which begins in 1932 and ends in 1961 in Ndjamena, and in 1963 in Maiduguri. Then the two localities experience a stable period of twenty years, which is followed by a generalised fall until 1991.
The latitudinal proximity of the cities of Maiduguri and Ndjamena, both located in Sudano-Sahelian zone, lets appear slightly differentiated average rainfall. These annual averages obtained indicate that Maiduguri is watered (605,4mm) than Ndjamena (583mm), a difference of 22,4mm of rain. The Kendall Tau-B test confirms a significant correlation with a correlation coefficient of 0.41; This confirms that other inherent factors in the environment influence the evolution of rainfall.

Keywords: Rain, latitude, decade, Maiduguri, Ndjamena

1. Introduction

For several decades, the earth is subject to an absolute disruption of the climate, this is due to the rise in temperature at different scales. This is not just a problem of the poor; it also affects countries in the south as in the north. The different parts of the world feel the event differently. Rainfall distribution for this purpose varies in the Sahel region and on a different scale, with the widespread resulting in low reliability of water supplies. In some localities, the temporal variations can be as high as 40%. This study is to highlight, if possible, the difference between two stations situated almost on the same latitude of the equator in the Sudano-Sahelian region and analyse it.
In particular, the arid and semi-arid areas that cover almost a third of the African continent only collect a small percentage of the overall flow. Changes over time are also wide and toggle between droughts and floods in some areas, making the averages very theoretical. This highly irregular and uneven distribution of rain water predates the appearance of man.
Between August 15 and September 17, 2012, the northern part of Cameroon has received exceptionally high rainfall that caused flooding in the North and Far North. The flooding caused considerable damage to irrigation infrastructure and to the Maga dam, and they destroyed the dam on the Logone over 25 km. A hundred thousand people were directly affected by the flooding in the area and have temporarily lost their livelihoods. The very high water levels have reached the threshold of 70 cm below the alert level of the Maga dam, degrading further the already fragile structure and endangering the downstream potential because of possible risk of dam failure.
The Sahel region is a Sudano-Sahelian type climate where the rains are rather scarce; in the month of August, there is a peak in rainfall in most cases. The rainy season does not exceed three months and rainfall is irregular from one year to another.

Methodology

Data

This exercise was made from the exploitation of daily precipitation data converted to the monthly and annual basis from Ndjamena and Maiduguri weather stations between 1932 and 1991 [2].

Location of the study area

The towns of Ndjamena and Maiduguri are among the most important cities in the Sahel region. The peculiarity of these centers is the very strong display. This is due to the difficult conditions and the chosen architectural modeling. They are located in a Sahelian tropical climate.

Ndjamena is located in the Midwest of Chad, between 12°06'59" North longitude and 15°04'20" east latitude, at the confluence of the Chari and Logone rivers, on the right bank of the Chari at a hundred kilometers, as the crow flies, south of Lake Chad (Figure 1). With a population of 1,092,066 inhabitants (auteur? 2012), it is the main traffic hub of Chad. The main roads. The main paved roads in the country are organised around the capital. Ndjamena is located 450 km from the second largest city, Moundou, and 750 km of Abeche, the largest city in eastern Chad.

Maiduguri with a population of over 1200 000 inhabitants, is located at 11 ° 80 'N and 13 ° 30' E in the North East of Nigeria. It is the capital of the state of Borno and distant of more than 1500 km southeast of Lagos. The city is located 100 km from the Cameroonian border in the far north (east), 200 km from the Niger border (north), and 250 km from the city of Ndjamena (east). This large city is bisected by the seasonal river Ngadda and has an altitude of 320 m.

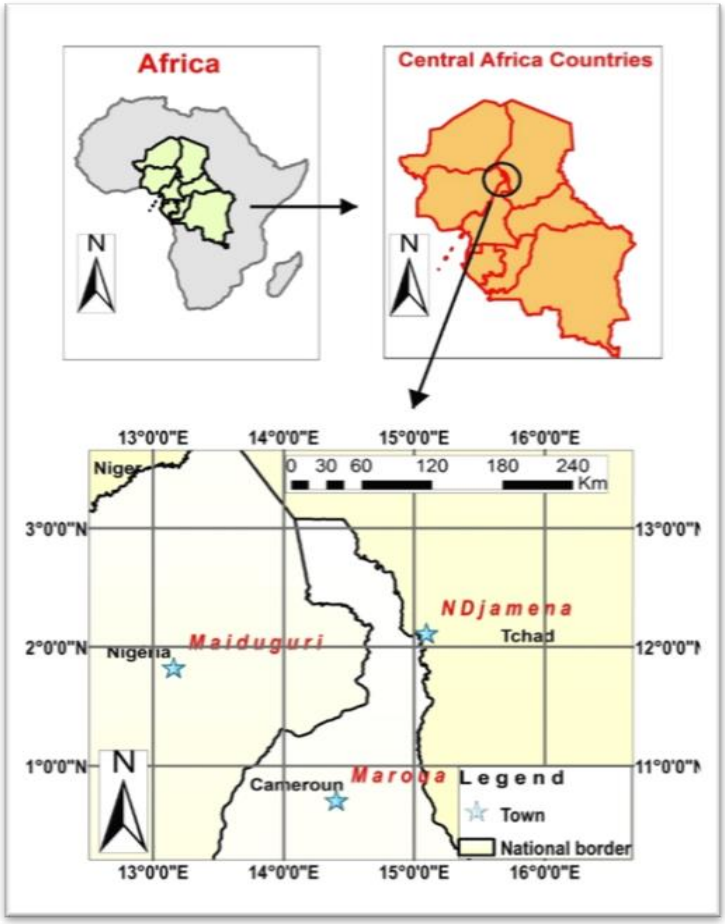

Fig 1: Location of Maiduguri and Ndjamena

Results

Evolution of rainfall in Maiduguri and in Ndjamena over the period of the study

The latitudinal proximity of cities of Maiduguri and Ndjamena, situated in Sudano-sahelian zone, leaves appear slightly differentiated average rainfall (Table 1). These annual averages obtained indicate that Maiduguri is watered (605,4 mm) than Ndjamena (583 mm), a difference of 22,4 mm of rain. The differences obtained are especially due to the extreme low rainfall recorded in Ndjamena (226 mm in 1984) despite the strong watering recorded in 1959 (989 mm).

In addition, a basic interpretation of the standard is "the average of studied values ". The average is occasionally confused with the median or the mode to explain the interannual irregularity. The net difference of the parameters studied explains the fickleness of rainfall in both stations (Table 1). In addition, to show the consistency of irregularity, Morel (1986) distinguishes hydrological standard, that is the average of a longer series in order to validate the most important regular occurrences, the meteorological standard that indicates a 30-year average (Ouédraogo, 2001). This allows calculation of normal rainfall which are sliding averages of 30 years, then succeed each other every 10 years for the dynamic analysis of the interannual rainfall data obtained, a comparison of normal periods studied is performed. Indeed, the 1951-1980 period is the reference of the World Meteorological

Organization (WMO) from which are analysed weather patterns (Ferry et al., 1998; Ouedraogo, 2001). But in view from the disposition of the series, we have not been able to make a clear comparison with the international standard time (1951-1980). The Tables 2 and 3 demonstrate the persistent difference between the characteristics of rainfall stations of Ndjamena and Maiduguri during the study period.

Table 1: Distribution of hydrological rainfall averages in Maiduguri and Ndjamena

Zones	Number of years	Minimum	Maximum	Average	Standard deviation
Maiduguri	60	234,00	951,00	605,4	149,1760
Ndjamena	60	226,00	989,00	583,1	158,3214

Table 2: Distribution of meteorological rainfall averages in Maiduguri and Ndjamena

Station	Maiduguri		Ndjamena	
Characteristics of 10 years	Average	Mode	Average	Mode
1932-1941	619,2	806	635,8	808
1942-1951	589,2	770	609,7	876
1952-1961	743,1	951	687,2	989
1962-1971	655,9	865	571,6	652
1972-1981	613,4	740	568,9	746
1982-1992	474	628	488,5	639

Table 3: Distribution of average weather rainfall of Maiduguri and Ndjamena

	Maiduguri		Ndjamena	
Characteristics of 10 years	Average	Mode	Average	Mode
1932-1961	650,5	951	644,2	989
1962-1991	581,1	865	543	746

Figure 2 shows a consistent decrease in rainfall in Maiduguri and in Ndjamena on the 60 years of study. The observed decline is confirmed by the negative trends of equations in the two study areas. Proceeding by Hubert segmentation method to determine the point of breaking rainfall, it appears that the period 1962-1963 to 1991 was the least watered simultaneously in both study areas (Figure 2).

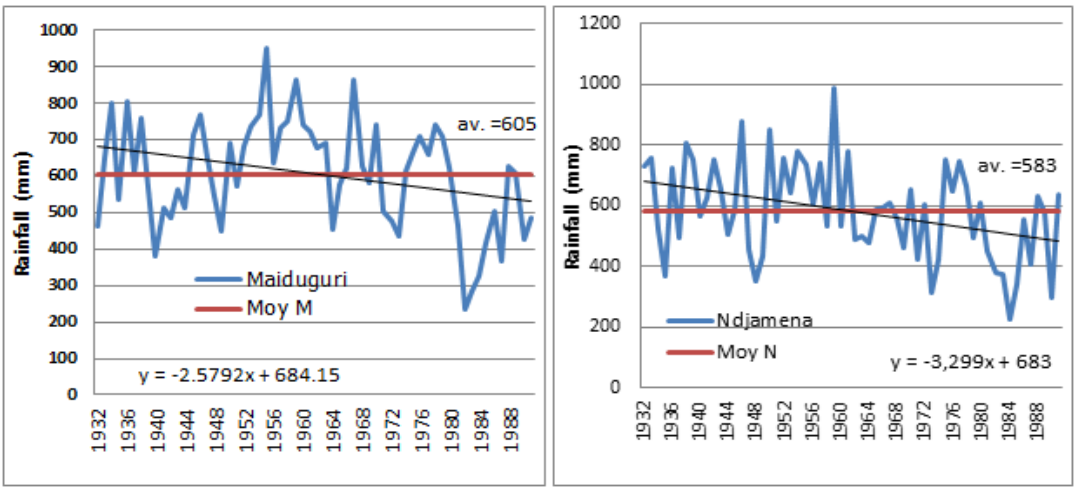

Figure 2: Evolution of the annual rainfall in Maiduguri and Ndjamena over the period of the study.

A more detailed analysis of break periods (Figure 3) shows reconciliation between the two study areas. It is more noticeable (552,8 mm) in 1963 in Maiduguri and (517,9mm) in 1962 in Ndjamena.

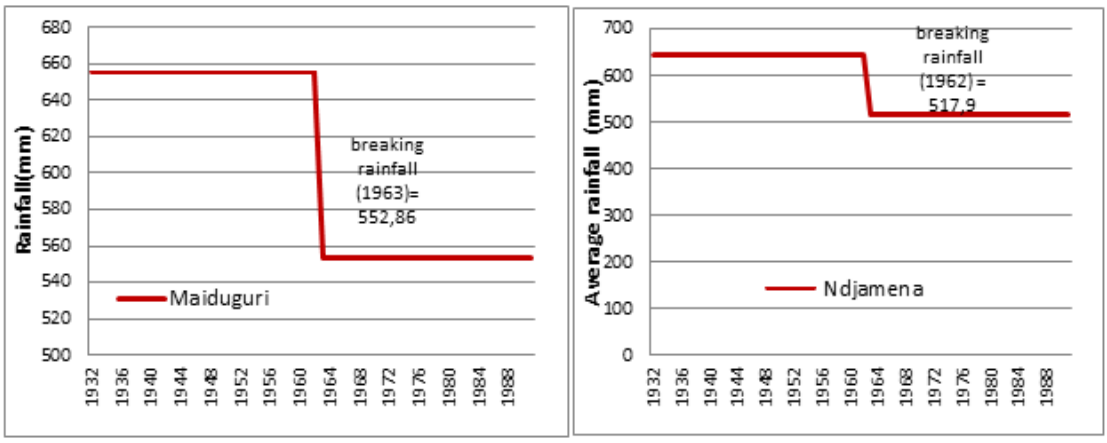

Figure 3: Ruptures observed in Maiduguri and in Ndjamena over the period of the study.

The change compared with the annual scale of deviations from the mean rainfall amounts of Maiduguri and Ndjamena (Figure 4) shows, for some years, alternating wet years with dry years. Of the 60 years observed, with the exception of thirteen years (1931, 1933.1936, 1938, 1941, 1942, 1944, 1946.1971, 1973, 1978, 1987 and 1990) which have rainfall amount changing asynchronously, other years experience changes in rainfall amounts ranging either in the direction of the increase or decrease in that of the two regions studied. The same figure shows that the two regions simultaneously have a wet phase between 1932 and 1962-1963, a dry phase which has practically developed for 30 years, 1963-1964 to 1991.

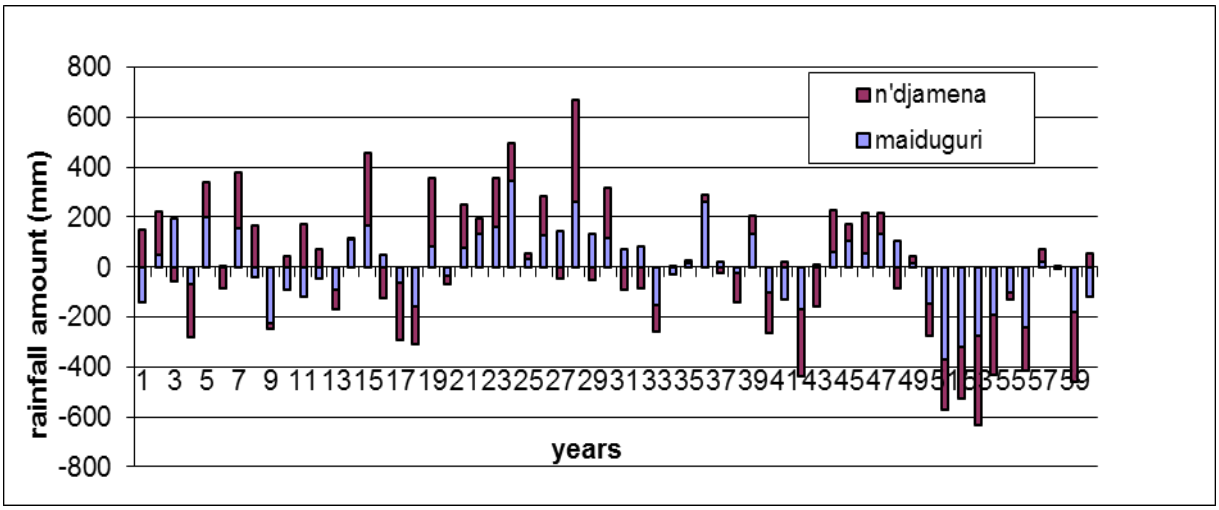

Fig 4: Differences in average rainfall amounts in Ndjamena and Maiduguri.

On the sixty years observed (Figure 5), 41 years show a positive rainfall index and the other 19 years have a negative index in Ndjamena. At Maiduguri in contrary, there is an observed positive index for 33 years and the other 27 years are negative. It follows from these observations that the rains are increasing in Maiduguri and Ndjamena over the period of the study. The evolution of the indices of deviations from the mean precipitation shows that the two regions have an alternation of a wet period between 1932 and 1963, which is followed by a dry period which begins in 1964 and ends in 1991.

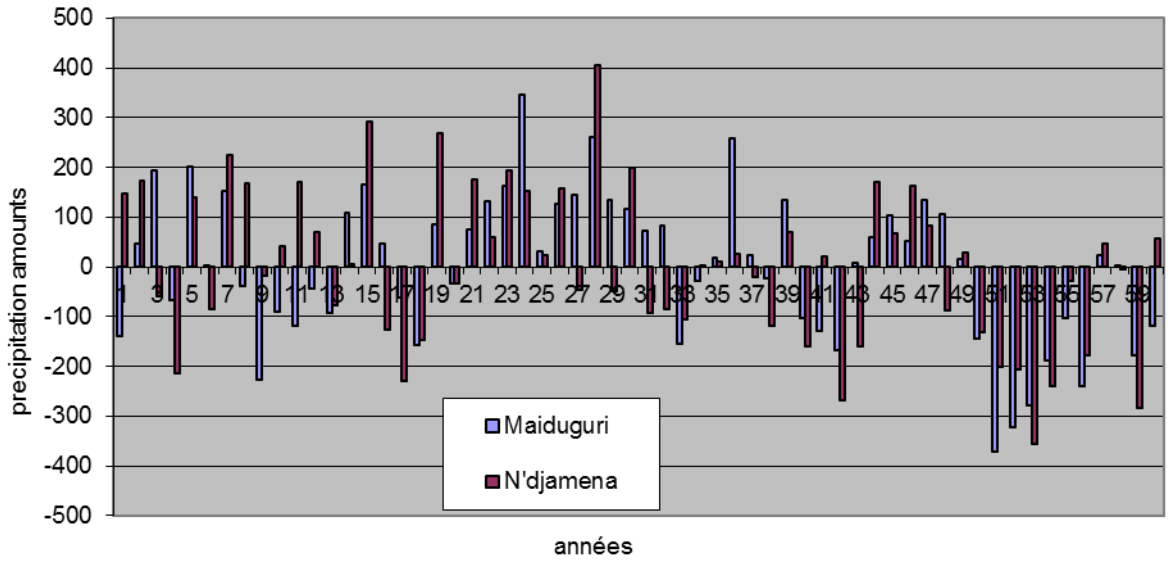

Fig 5: Index of deviations from the mean precipitation in Maiduguri and Ndjamena

At a decadal scale (Figure 6) and with the exception of the first two and the sixth decade when Ndjamena was wettest, the remaining four decades has a higher concentration of rainfall in Maiduguri. This trend shows that changes in rainfall amount have not been linear for both studied regions. Differences on an annual basis between the two regions are primarily observable in the first, second and sixth decades where Ndjamena was rainier than Maiduguri, with respectively 15, 20 and 14 mm of more rainfall in Ndjamena. The same figure shows that the third decade (1954-1964) has been the wettest for both regions. This decade records an average rainfall of 738 mm in Maiduguri and 702 mm in Ndjamena, a difference of 36 mm of rainfall.

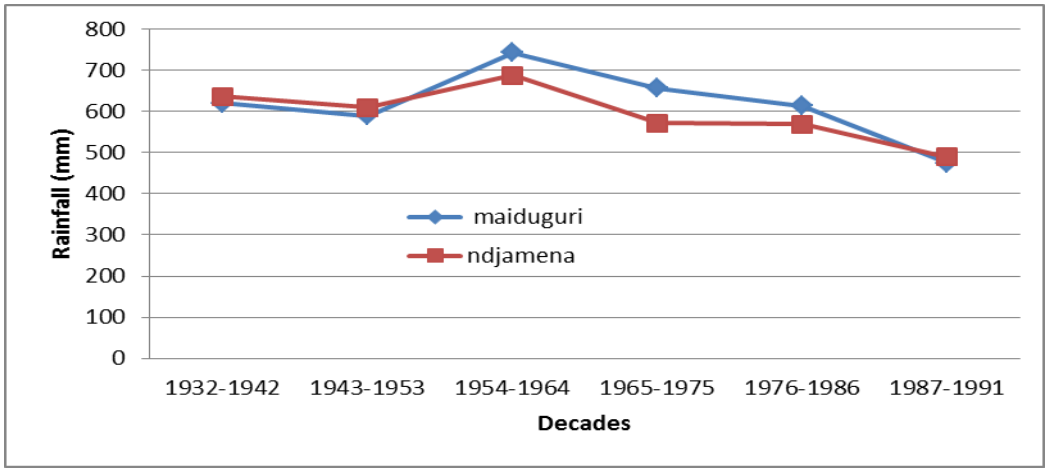

Fig 6: Decadal curves of amounts of rainfall in Maiduguri and Ndjamena 1932-1991

Table 2 shows that there are as many surplus years as there are deficit years in Maiduguri, or 08 years for each group, while the other 40 years record normal rainfall. Unlike Maiduguri, Table 3 shows that Ndjamena records excess rainfall, or 13 years against 09 years in deficit. The observations made between the two regions confirm the results obtained above, which indicates that Maiduguri was more watered than Ndjamena over the period of the study for wet years. In contrary, in deficit years, drought is more pronounced in Ndjamena than in Maiduguri.

Table 2: Maiduguri Rainfall from 1932 to 1991 (Barakat method)

Form	class	Estimation	Years	Total
Surplus years	Pi >pm+e	Pi > 754,78	1934, 1936,1938, 1946,1954, 1955, 1959,1967	08
Normal years	Pm-e<Pi<pm+e	456,18<pi<754,78	1932, 1933, 1935, 1937, 1939, 1941, 1942, 1943, 1944, 1945, 1947, 1948, 1950, 1951, 1952, 1953, 1956, 1957, 1958, 1960, 1961, 1962, 1963, 1965, 1966, 1969, 1970, 1971, 1972, 1974, 1975, 1976, 1977, 1978, 1980, 1981, 1986, 1988, 1989, 1991	40
Deficit years	Pi<pm-e	Pi <456,18	1940, 1949, 1964, 1982,1983, 1984, 1985, 1987	08

Table 3: Ndjamena Rainfall from 1932 to 1991 (Barakat method)

Form	class	Estimation	Years	Total
Surplus years	Pi >pm+e	Pi >741,42	1933, 1938, 1939, 1942, 1946, 1950, 1952, 1954, 1955, 1959, 1961, 1975, 1977	13
Normal years	Pm-e<Pi<pm+e	424,77<pi<741,42	1932, 1934, 1936, 1937, 1940, 1941, 1943, 1944, 1945, 1947, 1949, 1951, 1953, 1956, 1957, 1958, 1960, 1962, 1963, 1964, 1965, 1966, 1969, 1970, 1971, 1972, 1974, 1976, 1978, 1979, 1980, 1988, 1989, 1991	34
Deficit years	Pi<pm-e	Pi <424,77	1935, 1948, 1973, 1982, 1983, 1984, 1985,1987, 1990	09

The cumulative changes in precipitation for the two regions (Figure 7) shows a phase of growth that begins in 1932 and ends in 1961 and Ndjamena, began in 1932 to end in 1963 in Maiduguri. Both regions have a stable period of twenty years (1960-1980), which is followed by a generalised fall until 1991. The humification character of the town of Maiduguri is more pronounced than Ndjamena. In the study period, the cumulative annual total rainfall is higher in Maiduguri (36 329 mm) that in Ndjamena (34 982 mm), a difference of 1347 mm.

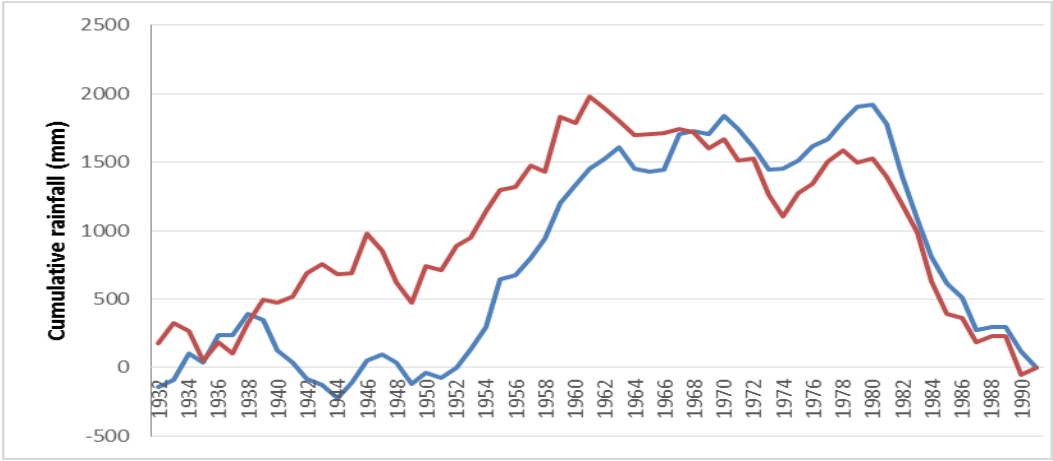

Figure 7: Cumulative rainfall curve in Ndjamena (brown) and Maiduguri (blue)

Although both towns are located in Sudano-Sahelian zone on the same latitude, 26 years show significant differences between the two study areas (Table 4). This observation confirms that the position on the same latitude do not always confer the same distribution of rainfall. In addition to the geographical position, other factors inherent to the local environment appear to influence the spatial division and distribution of rainfall as piezometry of the Lake Chad Basin (Figure 8).

Table 4: Differential observed between the two study areas

Years	dm-dn	Years	dm-dn
1932	-265	1962	188
1933	-105	1963	191
1934	276	1964	-26
1935	170	1965	-9
1936	83	1966	30
1937	112	1967	255
1938	-50	1968	67
1939	-186	1969	118
1940	-185	1970	88
1941	-110	1971	80
1942	-267	1972	-126
1943	-90	1973	122
1944	8	1974	189
1945	125	1975	-88
1946	-106	1976	58
1947	196	1977	-88
1948	189	1978	74
1949	12	1979	215
1950	-162	1980	9
1951	21	1981	10
1952	-80	1982	-148
1953	95	1983	-93
1954	-11	1984	102
1955	216	1985	74
1956	30	1986	-52
1957	-8	1987	-39
1958	214	1988	-2
1959	-123	1989	28
1960	205	1990	127
1961	-59	1991	-152

NB: dn - Ndjamena and dm- Maiduguri

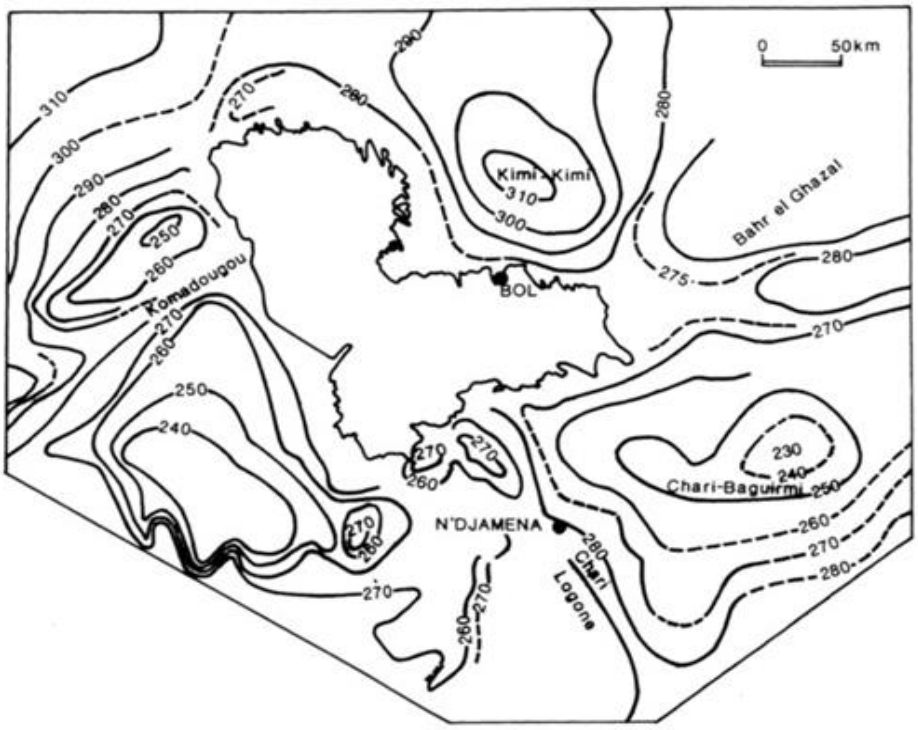

Fig 8: Piezometry of the Lake Chad Basin
Source: Carmouze

The confirmation Kendall Tau-B test (Table 5) indicates a correlation coefficient of 0.41, which is evidence that the two regions have a simultaneous evolution which is punctuated by distinct periods due to inherent causes of physical environment of the region.

Table 5: Correlation confirmation Kendall Tau-B Test between rainfall in Maiduguri and Ndjamena

		Maiduguri	**Ndjamena**
Maiduguri	Correlation coefficient	1,000	
	Sig. (bilateral)		
	N	60	
Ndjamena	Correlation coefficient	0,441	1,000
	Sig. (bilateral)	0,000	
	N	60	60

Discussion

Climate variability, particularly rainfall in West Africa and Central Africa in general and the Sahel in particular (20-10 N and 20 W-10 E), is well established (Michel Amani Kouassi and al, 2015). Sudano-Sahelian region has experienced in recent decades extreme variability and a sharp decrease in rainfall (Figure 9) (http: / the climatologie.free.fr). Despite their uncertainties, future precipitation trends show a decline of up to 20-30% especially in West and Central Africa (Maloba Makanga JD et al, 1997). The severity of the drought that will follow, will result in a reduction of water reserves available, farmland, changes in the length of the growing season and an increase in arid and semi-arid marginal for rainfed agriculture and pastures. Therefore, a decline in agricultural

yields of about 20-50% is observed. However, there remains therefore a large disparity between the Gulf of Guinea which future climate projections foresee for small variations in rainfall (Hulme M., 2001). These disparities are observable even in areas with the same longitude and latitude. As the two cities: Ndjamena and Maiduguri located at the same latitude. Is this geographical position confers to these two regions the same climatic provisions? The results between the two stations show remarkable differences in the temporal evolution of rainfall amounts. Several reasons justify these differences, including the effect of continentality. In fact Ndjamena is farther from the sea than Maiduguri, this position predisposes to a more dense and regular drying climate evoking the continentality index of Kromov. Another reason is that of the presence of different rivers and the existence of dams near Ndjamena and Maiduguri, giving each a special contribution to its global character. This plays an important role in air and increased evapotranspiration differently from one locality to another.

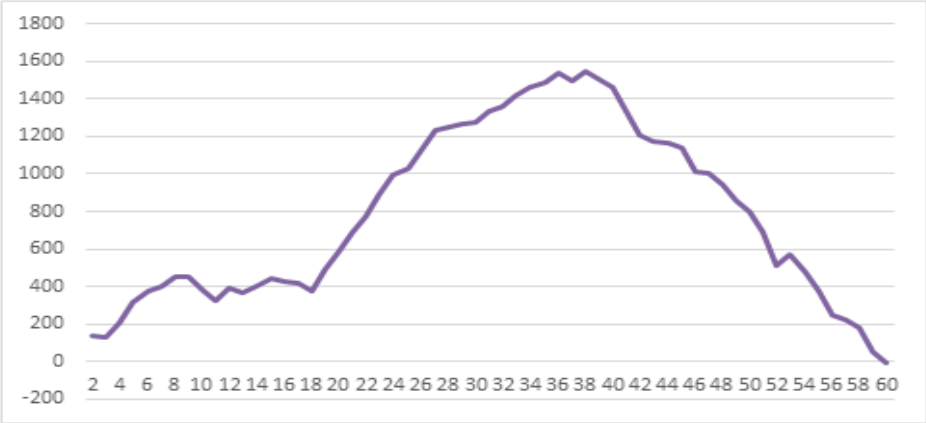

Fig 9: Evolution of rainfall in the Sahel from 1900 to 2010
Source: modified *JJASO.*

The analysis of rainfall characteristics helped to highlight the general downward trend in rainfall from the 70's that worsened over the following years. However, the entire Lake Chad Basin was not affected in the same way given the influence of local climate (R Gouataine Seingue and Laohoté Baohoutou, 2015). This result is in agreement with the results of the statistical tests applied for annual rainfall of two stations. This climate variability is reflected in a decrease in relative humidity and rising air temperatures, which results in a condition of the hydrological cycle in general and the formation of rain-bearing clouds in particular, from where weak annual rainfall amounts arise (Amani M et al 2015).

Conclusion

This study reveals that Ndjamena is located at 12°06'59" North longitude and 15°04'20" East latitude, while Maiduguri is 11 80 N and 13 30 E. Although both cities are located in Sudano-Sahelian zone on almost identical latitude, 26 years of study out of 60 present significant differences. This observation confirms that the position on the same latitude do not always confer the same distribution of rainfall. This is proof that in addition to the geographical position, other factors which are specific to the local environment of different cities influence the spatial division and distribution of rainfall.

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