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(Research Article)

The rainfall chronicles in the locality of Doba and its surroundings by the Standardized Rainfall Index (SPI) and Randomness Verification Tests

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Abstract

The study of the rainfall chronicles and its surroundings by the standardized rainfall index (spi) and randomness verification tests is of great importance for the management and planning of water resources. This work aims to study the variations of the rainfall regime over time by determining the precise years of rupture in the chronological series. This study considered rainfall data spread over 4 decades (from 1980 inclusive to 2019). These data were used to calculate the Standard Pluviometric Precipitation Index (SPI). These results show that the standardized rainfall indices vary from - 2.48 to 1.99 (extreme dry to very wet). The statistical methods of Pettitt, of Buishand, Bayesian of Lee and Heghinan show two rainfall sequences. A rain deficit sequence from 1980 to 2002 with an average of the indices in the order of (- 0.3113) and intercalated by years of severe droughts (1993, 1980 to 1987, 1993, and 2002). A surplus sequence in rainfall from 2003 to 2019 with an average index of 0.42. The rainfall variations observed have had a significant impact on the incoming water flows.

Keywords: Rainfall chronicles; Rainfall index; Statistical tests; Randomness verification tests; Doba

1. Introduction

On a global scale, climate variability plays a crucial role in the environment and is the cause of droughts. In Chad, different bioclimatic zones are identified [1], namely the Saharan zone, the Sahelian zone and the Sudanian zone, which is the subject of our study. The precipitation observed in these different areas is different. They cause either a drought or a flood [2], [3]. This rainfall variability considers several factors: precipitation, temperature, the sunshine, wind, potential evapotranspiration, and actual evapotranspiration. Several authors [2], [4] have relied on interannual precipitation data to assess droughts and rainfall deficits. Recent work has been carried out on the entire South zone [2]; however, this study is calibrated in a fixed time interval from 1963 to 2008. Given this work, our objective is to calibrate the analysis until 2019 and 1980. This analysis will allow us to obtain recent chronicles regarding rainfall deficits. Since rainfall patterns vary from one year to another, they are essential for assessing water deficit and surplus periods.

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2. Material and methods

2.1. Study framework

Located in southern Chad (Figure 2), the study area is between 16°47'16.891"E and 17°6'18.826"E longitude East; 8°34'12.959"N and 8°43'54.922"N latitude north. It belongs to the Sudano-Guinean domain [5], with climatic conditions influenced by the movement of air masses called the Inter-Tropical Front (ITF). The ITF moves south to North from January to August and returns south from September to December [6]. Two (2) seasons are identified in the year (Figure 1): a rainy season (May to October) and a dry season (November to April)

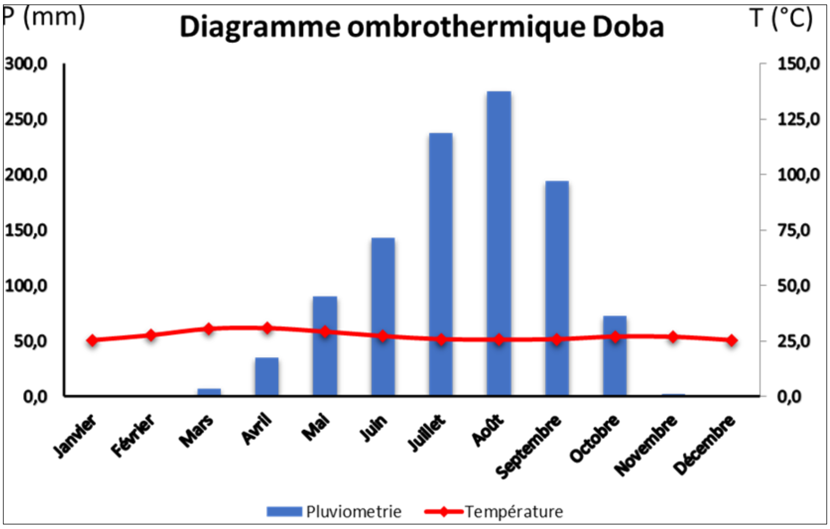

Figure 1 Ombrothermic diagram of the study area

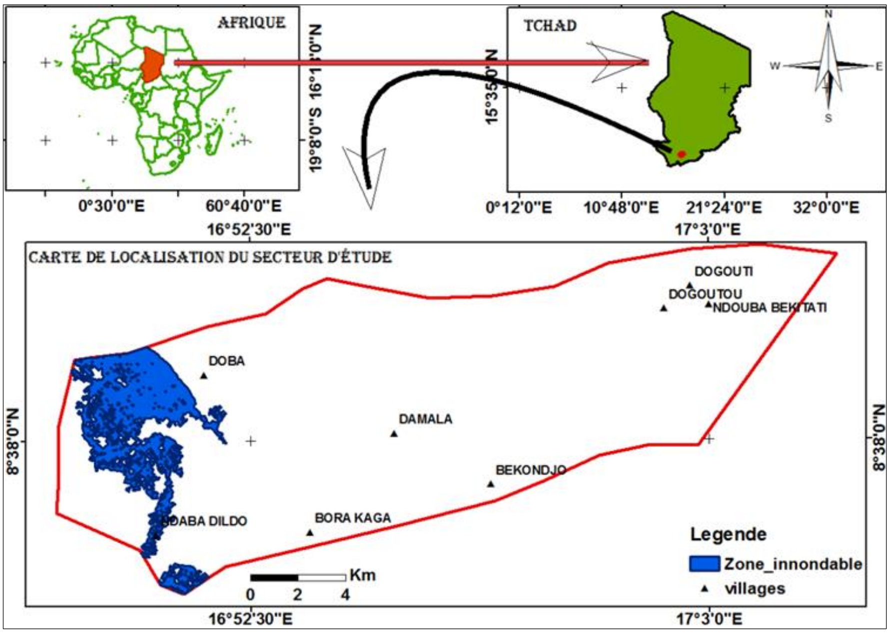

Figure 2 Location map of the study area

2.2. Methods

The interpretation of dry and wet periods results from interannual rainfall data. These different data made it possible to see the chronicles of precipitation covering the period from 1980 to 2019 (40 years). In the context of this present study, two methods are used to detect rainfall anomalies: one, based on the analysis of the evolution of standardized rainfall indexes (SPI) [7, 8], and the other on the use of statistical tests. In the latter case, we used the rank correlation test to verify the randomness or otherwise of time series, Pettitt's test [9], Buishand [10,11], Bayesian of Lee and Heghinian [12], and that of the segmentation of Hubert [13], for the detection of the years of breaks. A break can be defined by a change in the law of probability of the random variables whose successive realizations determine the time series studied [14]. Several software programs are used for this study: Excel, Khronostat 1.01, knowing that the precipitation index coefficients (SPI) were calculated using the MDM (Meteorological Drought Monitoring) software.

2.2.1. Calculation method for the Standardized Precipitation Index (SPI)

For the calculation of SPI, the formula used is:

$$SPI = \frac{1}{N} \sum_{J=1}^{Ni} \frac{P^i_J - \overline{P_J}}{\sigma j}$$

P^i_j the rainfall of the year i at station J,

$\overline{P_J}$ the average interannual rainfall of station J

σj, the standard deviation of the series of seasonal accumulations at station j and N_i the number of stations in a year i.

2.2.2. Application of statistical trend tests

Pettitt's test

This test detects breaks with specific dates and has the same confidence thresholds as the Rank test (99%, 95% and 90%). The Pettitt test is non-parametric and is derived from the MANNWHITNEY test.¶ If the null hypothesis is rejected, an estimate of the rupture date is given at time t defining the maximum in the absolute value of the variable Ut, N. ¶The absence of a cut of the series (X i) of size N constitutes the null hypothesis. The implementation of the test assumes that, for any instant t between 1 and N, the time series (x;) i = 1 at t and t + 1 at N belong to the same population. The variable to be tested is the maximum in the absolute value of the variable Ut, N defined by:

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

Dij = sgn (xi - xj) avec sgn(x) = 1 si x > 0; 0 si x = 0 et -1 si x < 0.

Bayesian method of Lee & Heghinian

The Bayesian method suggests a parametric approach. It requires a normal distribution of the values of the series. The absence of a break in the series constitutes the null hypothesis. The basic model of the procedure is as follows:

$$X_i = \begin{cases} \mu + \varepsilon_i \quad i = 1, \ldots, \tau \\ \mu + \delta + \varepsilon_i \quad i = \tau + 1, \ldots, N \end{cases}$$

Buishand's method

Buishand's procedure refers to the same model and assumptions as Lee and Heghinian's approach. If the null hypothesis is rejected, no estimate of the break date is proposed by this test. Assuming that there is a uniform prior distribution for the position of the breakpoint t, Buishand's U statistic is defined by:

$$U = \frac{\sum_{k=1}^{N-1} (S_K^*/D_x)^2}{N(N+1)} \qquad S_k = \sum_{i=1}^{k} (xi - x)$$

For k = 1, ..., Net Dx designates the standard deviation of the series. If the null hypothesis is rejected, no estimate of the break date is proposed by this test.

Hubert's method

A specific algorithm provides one or more break dates (possibly none) that separate contiguous segments whose means are significantly different concerning the Scheffé test. The confidence levels of his results are not known. Unlike Pettitt's test, it can report multiple breaks in the same series with their respective dates.

3. Results and discussion

3.1. Analyzes of rainfall anomalies

Interannual variations in rainfall in Doba are characterized by alternating wet, normal and dry periods. An extremely deficit period from 1980 to 1993 (figure 3), from 1993 to 2002 alternated with a few arid years in 1993, 1995, 2000, 1998, 2002. From 2003 to 2019, a wet period. The precipitation index ranges from -2.48 to 1.99, from extremely dry to very wet. The water inflows in the basin vary from 6.29 to 288 m3/s (table 2). The rainfall variability observed is strongly linked to the water flow observed (Figure 3). From 1980 to 2002, we observed low water flows following the rainfall deficits recorded in this period. The average water inflow from 1980 to 2002 is 80.92 m3/s against 119.51 m3/s in the 2003-2019 interval with a difference of 38.59 m3/s (table 1, 2). During these same time intervals, the average precipitation indices (IPS) are -0.31 mm against 0.42 mm with a difference of 0.11 mm between the two observed periods (table 1, 2). Suppose we refer to the interval from 1980 to 2002. In that case, there are periods of extreme rainfall deficits (from 1980 to 1987, 1993, and 2002) identified by the World Meteorological Organization (WMO) as being the periods of drought that marked southern Chad. This report has been confirmed by recent work [2]. There has been a considerable reduction in water in flood-prone areas [15], and a shrinkage of the Chari Logone system and the pendé.

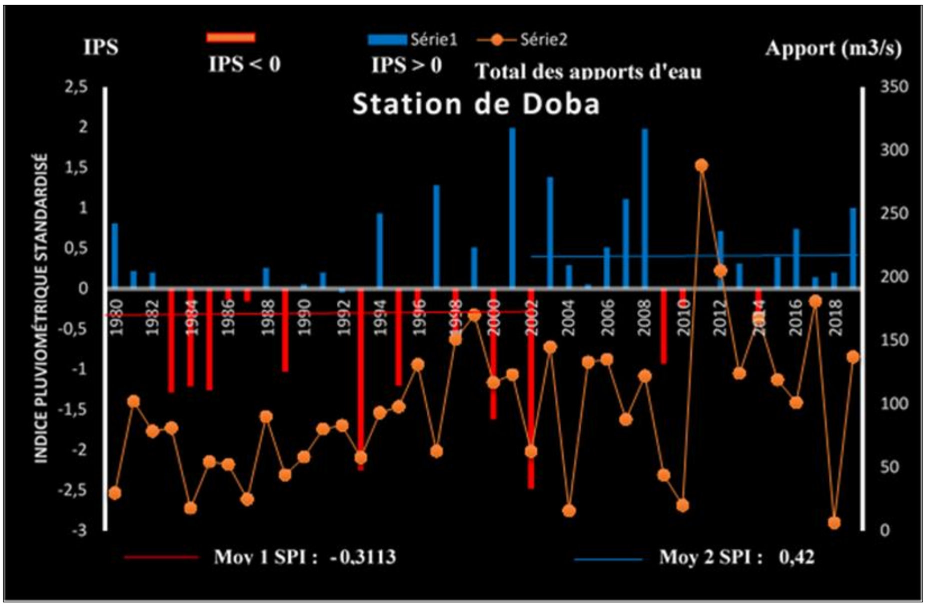

Figure 3 diagram of spi according to water supply

Table 1 Basic statistics of precipitation, spinnaker and water flow from 1980 to 2002. Source ANAM

	N	Minimum	Maximum	Total	Average	Standard deviation	Variance	CV
Precipitations	23	650.20	1426	22707.3	987.27	189.63	35962.65	0.192
SPI	23	-2.48	1.99	-7.16	-0.311	1.106	1.22	-3.55
Debit	23	17.80	170	1861.2	80.92	39.19	1536.01	0.4843

SPI: Standardized Rainfall Index; CV: Coefficient of Variation

Table 2 Basic statistics of precipitation, spinnaker and water flow from 2003 to 2019. Source ANAM

	N	Minimum	Maximum	Total	Average	Standard deviation	Variance	CV
Precipitations	17	873.90	1422.80	18895.90	1111.52	132.47	17548.48	0.1191
SPI	17	-0.93	1.98	7.17	0.42	0.70	0.493	1.664
Debits	17	6.29	288	2031.69	119.51	72.36	5236.9	0.6065

SPI: Standardized Rainfall Index; CV: Coefficient of Variation

Table 3 Types of drought classes according to the World Meteorological Organization (WMO) ranging from extremely dry to extremely wet

2.0 and over	Extremely wet
1.5 to 1.99	Very humid
1.0 to1,49	Moderately wet
-0.99 to 0.99	Close to normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Very dry
-2 and less	Extremely dry

3.2. Rupture and chronicles within rainfall series

Figure 4 presents the Pettitt test results applied to the Doba station's rainfall series. No break is observed in this test because the null hypothesis (no break) is accepted at all confidence levels (99%, 95% and 90%). But graphically, the ellipse shows from 2002 a variation in rainfall behavior. On the other hand, the rainfall series from 1980 to 2019 applied to the Lee and Heghinan test admits a precise breakpoint in 2002 (figure 5) with a posterior probability density of the position of this breakpoint equal to 0.0830 (table 4). Buishand's test gives the results in Figure 6. The null hypothesis (no break) is accepted at the different confidence levels (99% and 95%) and rejected at the 90% confidence level. The curve overflows the ellipse at the 95% and 90% significance thresholds, but we observe a variation in the regime from 2002, although this test does not show a clear break in this rainfall series. Hubert's test shows an average of four (4) decades of precipitation equal to 1040.080 mm, a standard deviation of 177.075 and a level of significance of the Scheffe test of 1%. The various tests identified the significant rainfall variations from 1980 to 2019. Although the trials of Buishand, Hubert, Pettitt did not precisely locate the year of ruptures like that of Lee and Heghinann, they confirm the variations in the rainfall regime and the severe droughts observed in the years before 2002, which impacted Chad and played a significant role in the shrinkage of hydrological systems in the Lake Chad basin [3].

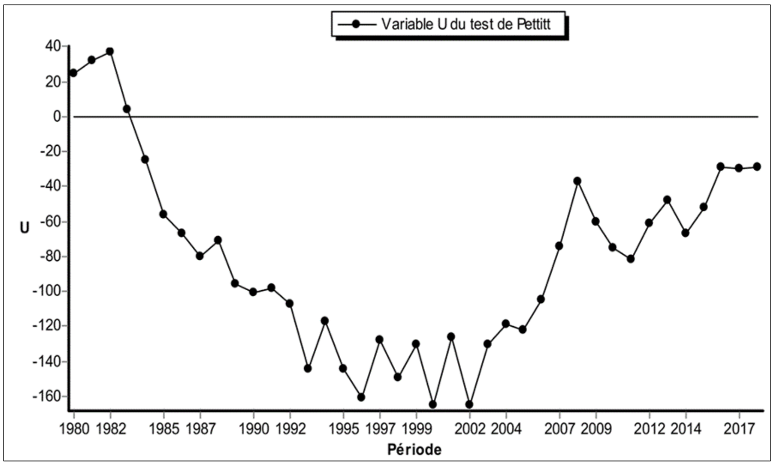

Figure 4 Determination of the rupture period in Doba by the pettitt test

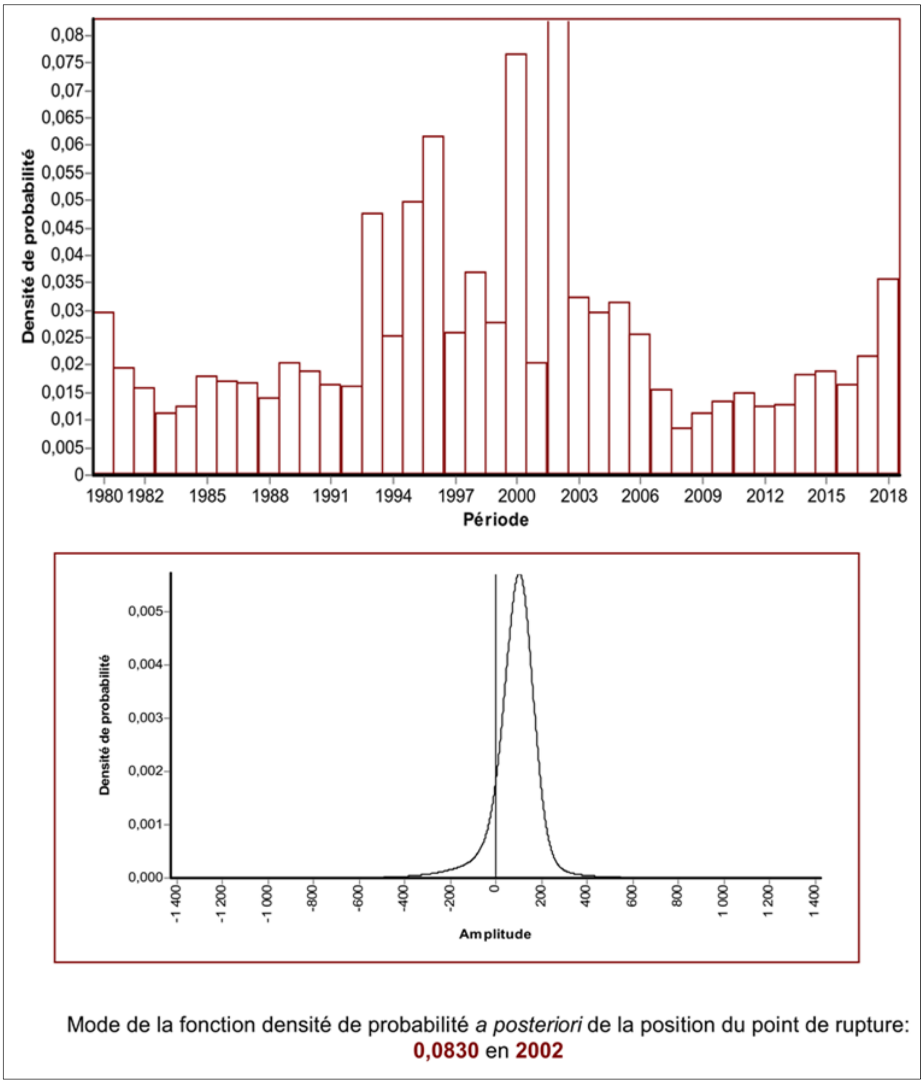

Figure 5 Determination of the rupture period in Doba by the Bayesian method\

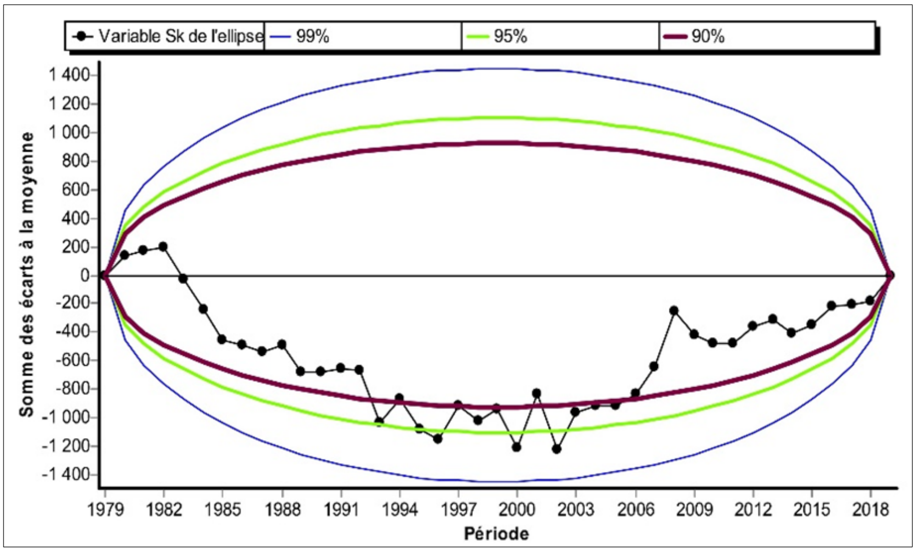

Figure 6 Determination of the rupture period in Doba by the Buishand test

Table 4 Break in rainfall series according to the Lee and Heghinian Bayesian test

Station	Breaking year	Associated probability
Doba	2002	0.0830

Table 5 observed periods of severity

Drought sequences	Duration (years)	values of SPI (Maximum intensity)	Type of breaks
1980 - 2002	23	-2.48	Extremely dry
2003 - 2019	17	-0.93	Close to normal

4. Conclusion

This study of rainfall series over four decades (1980 to 2019) has enabled us to highlight a few chronic years of precipitation. These chronicles observed have a negative impact on the environment. Standardized Rainfall Indices (SPI) study shows two years with extremely low rainfall (1993, 2002). The Lee and Heghinian test showed precisely one year of rupture observed in 2002. Before this year, a period was identified as a severe chronic period (1980 to 1993). The enormous decrease in precipitation during the first two decades (1980 – 2002) directly affected the water inflows in the hydrogeological basin.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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