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Drought from the 1970s to the 1990s and its Influence in the Tropical City of Beni, Eastern DR Congo

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ABSTRACT

Regional and local climate variability has serious consequences on water resources, ecosystems, and socio-economic activities. With the inexistence of rainfall stations, it is important to reconstruct the past climate with existing data and explore new possibilities for monitoring future climate evolution in the tropical city of Beni. The objective of this paper is to date the 1970-1990 drought and determine the rainfall trend in the tropical city of Beni. To this purpose, a 45-year rainfall time series (period 1974-2019) was analyzed using the Standardized Precipitation Index (SPI). The results of the paper indicate that the average annual rainfall ranges from 693 to 3080 mm with an average of 1827 ± 480.65 mm. The Hubert segmentation procedure applied to the rainfall series reveals three breaks (sub-periods): 1974-1979 (mean 1205.7 mm), 1980-2007 (mean 1736.68 mm), and 2008-2019 (mean 2348.01 mm). After the 2000s, the analysis shows an increasing trend in rainfall. A rainfall deficit of 35.20% is recorded during the period 1974-1979 compared to the period 1980-2007 and 22.61% for the period 1980-2007 compared to the period 2008-2019. The results of this study demonstrate that the city of Beni would have suffered from the drought of the years 1970-1990. Future research should focus on the future evolution of rainfall. However, understanding this future evolution requires long-term data, which is not the case for the tropical city of Beni. Therefore, there is a need for policymakers in collaboration with scientific actors to install meteorological stations to collect climate data.

INTRODUCTION

Drought is a naturally occurring climate phenomenon that impacts human and environmental activity worldwide (Sheffield et al., 2009). Drought is among the natural hazards and disasters that carry significant costs for many governments around the world (Sheffield et al., 2009; Wang et al., 2014). It is one of the most complex and scientifically least understood natural disasters (Spinoni et al., 2014, 2019; Wang et al., 2014).

Drought is a phenomenon that can affect geographically larger areas and last much longer unlike other natural hazards (Yacoub & Tayfur, 2020). Currently, drought episodes are becoming more frequent and intense due to climate change (Ekolu et al., 2022; Yacoub & Tayfur, 2020). Drought induces social, economic, and social impacts. These impacts are manifested in the short or long term and affect vulnerable people (poor populations) with high intensity (Batterbury & Warren, 2001; Edossa et al., 2014; Oloruntade et al., 2017).

The current global climate is in a state of continuous change. Studies show that rainfall in

Africa over the 20th century has been characterized by a decreasing trend, with a more pronounced decrease in Sahelian countries (Hagos & Cook, 2008; Hulme, 2001; Nka et al., 2015; Oyerinde & Olowookere, 2018; Sidibe et al., 2018). Unlike other parts of Africa, the Saharan region has always experienced alternating wet and dry periods (Ozer et al., 2010). Three major drought periods affected all Sahelian countries during the 20th century: the drought of the 1910s, the drought of the 1940s, and the great drought that began in 1968 (Hagos & Cook, 2008; Niang et al., 2008; Ozer et al., 2003, 2010) and lasted approximately 20 to 30 years with extreme rainfall deficits (Hulme, 2001; L'Hôte et al., 2002; Ozer, 2002). One study shows that for the period 1968-1997, rainfall in the Sahelian region of West Africa decreased by up to 37% compared to rainfall in the period 1931-1960 (Sidibe et al., 2018). In this same idea, Ozer (2002) also confirms the non-stationarity of rainfall patterns in Sahelian countries between the periods 1921-1968 and 1968-1998. This author found that rainfall decreased by 20-25% and nearly 110 mm between these two periods, with an average annual rainfall of around 488 and 381 mm respectively (Ozer, 2002). Other studies also show a decrease in rainfall of the order of 20-30% in the Sahel between the decades preceding the accession of many Sahelian countries to independence (i.e., the period 1930-1950) and the decades following independence (period 1970-1990) (Batterbury & Warren, 2001; Hulme, 2001).

Compared to other periods, rainfall variations in the post-1990 period are less well understood, given the lack of data. This has led to controversial interpretations regarding the end of the Sahel drought (Sidibe et al., 2018). Part of the scientific community believes that the drought in the Sahel region ended during the 1990s (Hagos & Cook, 2008; Ozer et al., 2003, 2010). While other research estimates that the drought period continued beyond the 1990s (Descroix et al., 2009; L'Hôte et al., 2002; Mahe et al., 2013; Ozer et al., 2003). These contradictions at the end of the drought partly reflect significant changes in the spatial distribution of rainfall, which make conclusions highly dependent on the characteristics of a given region, years, and even months considered in the study (Sidibe et al., 2018).

In Central Africa, the rainfall break in the 1970s was less marked compared to West Africa (Nguimalet et al., 2022). Although this break was less marked, it had a significant influence on the hydrological regimes of the main rivers in Central Africa (Laraque et al., 2001; Orange et al., 1997). Although research has confirmed a reduction in rainfall regimes since the 1970s in the Sahelian region, studies on Central Africa are still fragmentary (Laraque et al., 2001). Findings from the study by Mahe et al. (2013) indicate that the climate in Central Africa has changed since 1970. However, this same study shows that this rainfall returned to a normal trend after the 2000s. An example of the decrease in river hydrological regimes due to the drought of the 1970s-1990s is the Congo River.

According to Nguimalet et al. (2022) report that after a hydrological deficit observed in the 1980s, the flow of the Congo River returned to normal starting in the 1990s. Studies show that the decrease in average annual rainfall in the tropical rainforest zone was about 4% in West Africa, 3% in northern Congo, and 2% in southern Congo for the period 1960-1998 (Babatolu et al., 2013).

Current trends in climatic factors illustrate that Africa could be affected by climate change and many project an increase in drought in some areas (Ghebrezgabher et al., 2016; Nicholson et al., 2018). Some studies show that such a climate change appears to have already occurred in East Africa based on the high inter- and intra-annual variability in rainfall (Karanja et al., 2017; Nicholson et al., 2018). This change has induced the occurrence of more and more extreme events in terms of droughts and floods (Karanja et al., 2017). According to Karanja et al. (2017), East Africa has experienced droughts in the last 20 years: 1983/84, 1991/92, 1995/96, 1999/2001, 2004/2005.

However, climate change in East Africa still remains poorly documented due to the low density of weather stations that do not allow for a better relevant description of climate change at the local and regional levels (De Longueville et al., 2016). In addition, there is a lack of high-quality, long-term climate data in Africa compared to other regions of the world (De Longueville et al., 2016; Mahe et al., 2013). In this context, the study of climate change becomes a daunting task in these areas lacking weather stations. This limitation is even more worrisome insofar as the detection of changes in climatic and hydrological processes is very complex and inevitably relies on the analysis of long time series.

Drought in the Sahelian countries and the tropical countries of West and Central Africa during the 1970s did not spare the Democratic Republic of Congo (DRC). For this vast Central African country, Kalombo (1995) shows that the rainfall deficit of the humid tropics extended over the western part of the Congo Basin, to the Kasai, and reached the southeastern part of the DRC (the low plateaus of Katanga and the southern edge of the Cuvette Centrale) during the years 1980-1994.

In the cities of the northeastern part of the DRC (Butembo, Beni) the dating of drought periods is less documented although this region is characterized by high rainfall variability associated with the Intertropical Convergence Zone (ITCZ) (Sahani et al., 2012). Both urban and rural populations in this part observe signs such as the late and sometimes abrupt return of rains with or without showers and hail, high daytime temperatures, unusual drought beyond three months, and disturbance of the agricultural calendar every year (Cirimwami et al., 2019).

Against this background, it is important to understand the phenomenon of drought in this area. It is in this perspective that this research tends to study the evolution of rainfall in the city of Beni. In this town, which is located in a humid tropical climate with evergreen forests (Bweya et al., 2019), climate information is almost non-existent. With the current development, this city does not seem to be spared from rainfall disturbances as a result of climate change.

Unfortunately, it is difficult to study the climate with the absence of time series in this city. Meteorological stations are almost non-existent. Some stations there have short time series with many missing values. Therefore, it is important to fill these gaps because the information from the analysis of the dynamics of extreme weather events such as drought can be very useful for water resources planning and management (Oloruntade et al., 2017). In addition, assessment of drought conditions is essential for water supply planning, irrigation system development, food security programs, hydropower generation, water quality management, and waste disposal systems (Karanja et al., 2017). Considering the above-mentioned problem, the objectives of the paper are the following: (1) Determine if the tropical city of Beni experienced a significant rainfall deficit during the 1970-1990 drought; (2) Determine the trend and identify breaks in rainfall in the city of Beni since 1974.

MATERIALS AND METHODS

Study Area

Beni is the second largest city in northeastern DRC, located near the Virunga National Park on the plateau of Mount Ruwenzori (5,109 meters above sea level) in North Kivu province. This city is located at 0° 29' 18" north latitude and 29° 27' 32" east longitude (Figure 1).

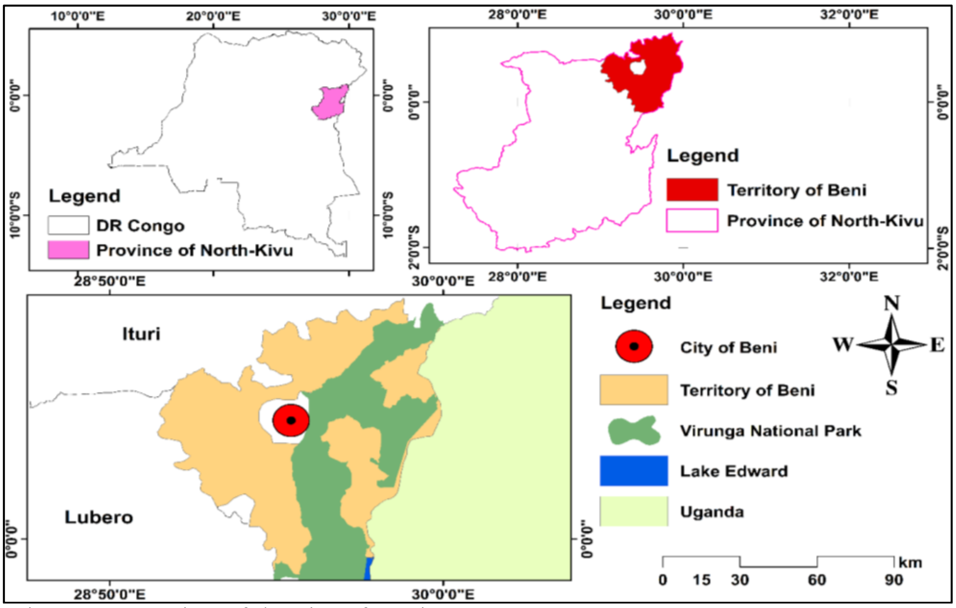

Figure 1. Location of the city of Beni

The altitude of the city of Beni varies from 850 m to 1763 m with an average of 1120 m. It is located 70 km from Kasindi, a city that borders Uganda (Figure 1). In 2015, the population was estimated by the National Institute of Statistics to be 355,289 with a density of 1928 inhabitants/km^2. The area of the city of Beni is estimated at 184 km^2. Three types of vegetation characterize the landscape of this city and its surroundings: (i) open forest combined with wooded and grassy savannahs in the Semuliki plain, (ii) montane forest located in the Mount Ruwenzori area, and (iii) ombrophilous and evergreen forest typical of the central forest domain of the Congolese basin (Bweya et al., 2019). The city of Beni is characterized by a tropical savannah climate (or wet and dry tropical climate) is a tropical climate characterized by an average temperature above 18°C according to the Köppen classification. This climate is characterized by heavy rainfall interrupted by two dry seasons in January-February and June-August, respectively (Moïse et al., 2022; Ndavaro et al., 2020). However, rainfall-thermometer fluctuations are significant. They vary between 1200-2000 mm (average 1600 mm) of rainfall and 20-30 °C (average 25 °C) (Bweya et al., 2019).

The soils derived from the various rocky substrates encountered in Beni are mainly formed of kaolinitic materials. The essential feature of these soils is the presence of excellent quality soils but with a high sensitivity to erosion (Kujirakwinja et al., 2007). The existence of *hygrokaolisols* and *hygro-xero-kaolisols* is also noted. These *hygrokaolisols* are soils without profile drying. They have a saturation rate in cations generally lower than 25% (Moïse et al., 2022). In contrast, Hygroxerokaolisols are soils with temporary drying of the profile. They have a saturation rate generally between 30 and 50% (Moïse et al., 2022). Chemically, Beni soils in general are acidic and low in calcium under forest cover but become basic and high in calcium under cultivation. Soils have a nitrogen mineralization rate of 5% and a water pH ranging from 5.5 to 6.1 (Moïse et al., 2022).

Data Acquisition

Monthly rainfall data were obtained at the station of the industrial company ENRA Sarl/Beni (Enzymes Raffiners Association) which is involved in the exploitation and export of wood in the region. The time series begins in 1970, but due to missing data from 1971-1973, the study considered the period from 1974 to 2019, or 45 years. Due to the war that has been raging in the region for more than two decades, the archives, sabotaged by armed groups, are non-existent. Only the monthly rainfall series was found and used in this article.

Rainfall Deficit: Standardized Precipitation Index (SPI)

The rainfall deficit for the time series was studied using the Standardized Precipitation Index (SPI) (Mckee et al., 1993). The SPI is uniquely related to probability and is normally distributed and thus can be used to monitor wet and dry periods. It is normalized so that wetter and drier climates are represented in the same way (Mckee et al., 1993). Using the SPI as an indicator, a functional and quantitative analysis can be performed to define drought for each time. A drought event for time scale *i* is defined here as a period during which the SPI value is continuously negative and the SPI reaches a value of -1.0 or less. The drought begins when the SPI first falls below zero and ends when the positive SPI value follows a value of -1.0 or less (Mckee et al., 1993). Its formula is as follows:

$$SPI=\frac{Pi-P}{\sigma}$$

With *Pi* the annual rainfall of year *i*; *P* the average rainfall of the period considered and σ the standard deviation of the time series. Thus, a year will be considered normal if its index is between -0.1 and +0.1. It will be said to be wet if its index is greater than 0.1 and dry below -0.1. This interval remains open to criticism since it is relatively small so normal years are very few. However, it does provide a good distinction between dry and wet years (Lawin et al., 2011). Drought intensity is arbitrarily defined for SPI values with the categories presented in Table 1.

Table 1. Interpretation of SPI values (Mckee et al., 1993)

SPI values	Drought category
0 to -0.99	Mild drought
-1.00 to -1.49	Moderate drought
1.50 to -1.99	Severe drought
≤ -2.00	Extreme drought

Detection of breaks and trends

1. Mann-Kendall test (MK test)

The Mann-Kendall test is used to identify trends for a given time series. The main objective of the non-parametric MK test is to statistically investigate whether there is a monotonic upward or downward trend in the variable of interest over time. A monotonic upward trend means that the variable increases steadily over time. Similarly, a monotonic downward trend means that the variable decreases consistently over time (Yacoub & Tayfur, 2020). In this test, the null hypothesis H_0 and the alternative hypothesis Ha, respectively, refer to the non-existence and existence of the trend.

2. Pettitt's test

Non-parametric Pettitt test (Pettitt, 1979) aims to detect breaks in time series. Known for its robustness, this test is derived from the formulation of the Mann-Whitney test. The absence of a break in the time series is the null hypothesis H_0 (Paturel et al., 2004; Tirogo et al., 2016). This test is particularly sensitive to a change in mean and, if the null hypothesis of series homogeneity is rejected, it provides an estimate of the break date. The results of this test are analyzed through the break date and the p-value (α), which indicates the significance level of the break. The p-value indicates whether the breakpoint probability is statistically significant relative to a given threshold. Non-parametric statistical tests are most commonly used in hydrology because they make no assumptions about the distribution of the data, making them robust (Tirogo et al., 2016).

3. Buishand's *U* statistic

Buishand's statistic (Buishand, 1982, 1984) is derived from an original formulation given by Gardner (1969) to establish a two-sided test for a break in the mean at an unknown time. The Buishand test is parametric, assuming normality of the series, non-autocorrelation, and constancy of variance on both sides of the eventual breakpoint. This test is effective in detecting a break in the middle of the series, but it does not provide an estimate of the breakpoint (Laraque et al., 2001).

4. Hubert's segmentation

Segmentation using the Scheffé test implicitly assumes the normality of the time series. This method consists in splitting the series into m segments (m >1) in such a way that the mean calculated on any segment is significantly different from the mean of the neighboring segment(s). Such a method is appropriate for finding multiple changes in the mean (Paturel et al., 2004). This segmentation procedure can be viewed as a stationarity test (Hubert et al., 1989). The null hypothesis (H0) of this method assumes that the time series is stationary. Indeed, stationarity is related to the duration of the observations. If the procedure does not produce an acceptable segmentation of order greater than or equal to 2, then the null hypothesis is accepted. No significance level has been assigned to this test (Paturel et al., 2004).

Moreover, the combination of these different methods is justified by the fact that the Pettitt and Mann-Kendall tests are homogeneity tests whose null hypothesis indicates that a time series is homogeneous between two dates of a time series and according to two different distribution laws. These tests are known for their robustness but do not allow the detection of more than one break in a time series. On the other hand, Hubert's segmentation test gives the year of the different breaks observed in the series with the means and standard deviations of the different segments (Nguimalet et al., 2022). The trend and break tests on the rainfall series were performed with Khronostat 1.01 software developed by the Institut de Recherche pour le Développement (IRD)/France (IRD, 2002) and XLSTAT (Trial version) (Addinsoft, 2023).

RESULTS AND DISCUSSION

Monthly Precipitation Trends

Analysis of Figure 2 shows variations in rainfall within and between months. Overall, it can be seen that the monthly total is below 100 mm for January and February. From March to December, the amount of rainfall exceeds 100 mm, but with relatively low rainfall in June and July.

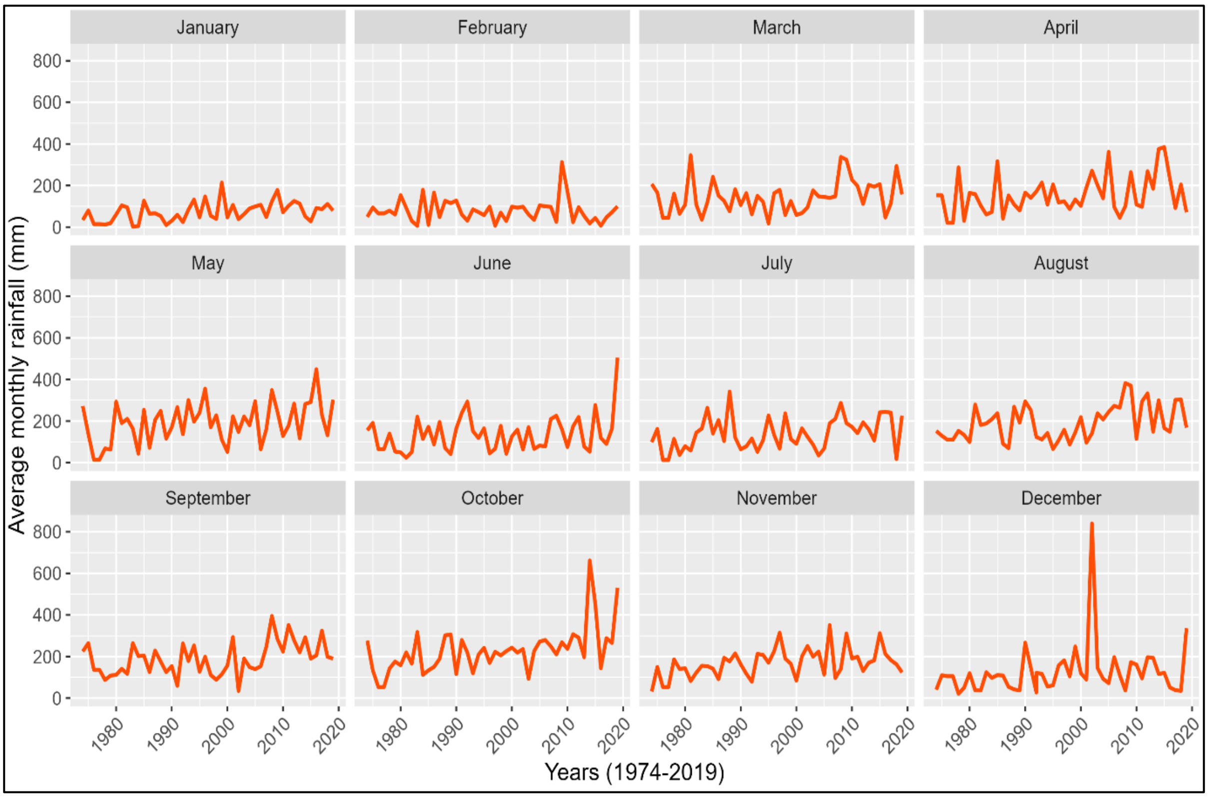

Figure 2. Inter- and intra-annual variations in observed precipitation

The average cumulative daily rainfall during August, September, and October is high compared to the other months (Table 2). Despite the absence of temperature data, this table reveals that although the dry season does not seem to be well marked, the months of January-February and June-July correspond to the dry season (Table 2).

Table 2. Distribution of observed rainfall by month

Months	Rainfall (mm) (period 1974-2019)			
	Minimum	Average	Standard deviation	Maximum
January	2.24	72.87	46.85	214.1
February	6.09	78.89	56.28	312.8
March	17	145.94	78.58	346.05
April	20.12	156.07	92.43	384.6
May	13.66	192.63	97.01	449
June	23.47	135.72	88.33	504.8
July	12.32	139.92	78.12	341.7
August	65.2	191.25	83.58	382.2
September	34.6	189.57	78.09	395.2
October	53	229.73	110.82	662
November	31.96	168.98	69.23	351.4
December	21.08	125.32	127.28	840

Rainfall for the period 1974-2019 provides a mean annual cumulative rainfall ranging from 693 to 3080 mm with an average of 1827 ± 480.65 mm. The standard deviation is large, which provides information on the great variability of rainfall in this region. The interpretation of the third quartile of the distribution, for 75% of the years between 1974 and 2019, recorded a mean annual amount below 1994 mm/year.

Standardized Precipitation Index (SPI)

The rainfall deficit (Figure 3) is more pronounced for the period 1976-1977 with SPI values below -2 (extreme drought). The year 1979 was characterized by a severe drought (SPI value equal to -1.50 to -1.99) and the years 1982 and 1986 are characterized by a moderate drought (SPI value equal to -1). Overall, after the 1990s, there is an increasing trend in precipitation during the 2000s (Figure 3). The trend in SPI values is more or less similar to that observed by many authors in the humid tropics during the 1970s-1990s, although the intensity is low.

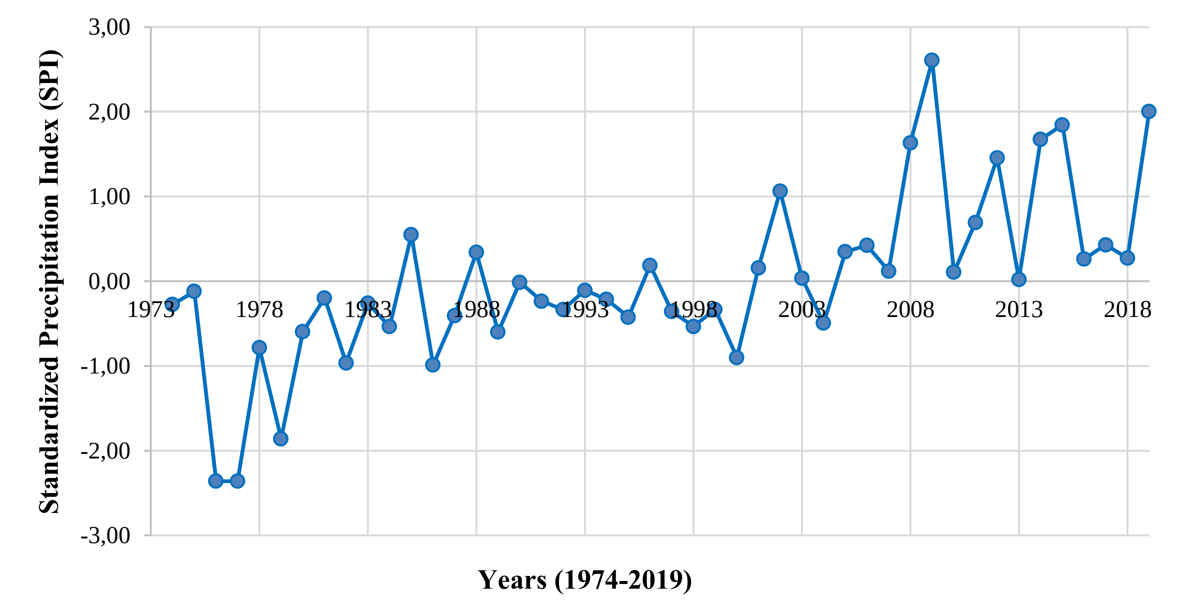

Figure 3. Standardized Precipitation Index of the ENRA station (between 1974 and 2019)

Table 3. Precipitation trend parameters (Sen's method) between 1974 and 2019

	Value	Lower limit (95 %)	Upper limit (95 %)
Slope	20.80	13.11	30.51
Constant	-39714.60	-49415.59	-32064.45

Determination of the Trend and Break in the Time Series

According to the results of the Jarque-Bera test, the rainfall series respects normality (df =2, value=1.994, p-value=0.378). This trend in rainfall in Beni City is increasing (Table 3). Since the calculated p-value is below the significance level alpha=0.05 (Table 4), the null hypothesis H0 of the Mann-Kendall test must be rejected and the alternative hypothesis retained. The series is random and we conclude that there is a trend in the rainfall series. However, since the calculated p-value is below the significance level alpha=0.05, we must reject the null hypothesis (H_0) and retain the alternative hypothesis Ha of the Pettitt and Buishand tests (Table 4).

Table 4. Results of the Mann-Kendall, Pettitt, and Buishand tests

Mann-Kendall test		Pettitt test		Buishand test	
Tau of Kendall	0.526	K	437	Q	14.82
S’	544	t	2000	t	2000
Var(S’)	11154	p (bilateral)	<0.0001	p (bilateral)	<0.0001
p (bilateral)	<0.0001	α (alpha)	0.05	α (alpha)	0.05
α (alpha)	0.05				

The Pettitt and Buishand tests show two periods in the precipitation series (Figure 4): the 1974-2000 period with an average of 1566 mm and the period after the 2000s with an average of 2198 mm, i.e. an increase in precipitation of 28.75% compared to the previous period.

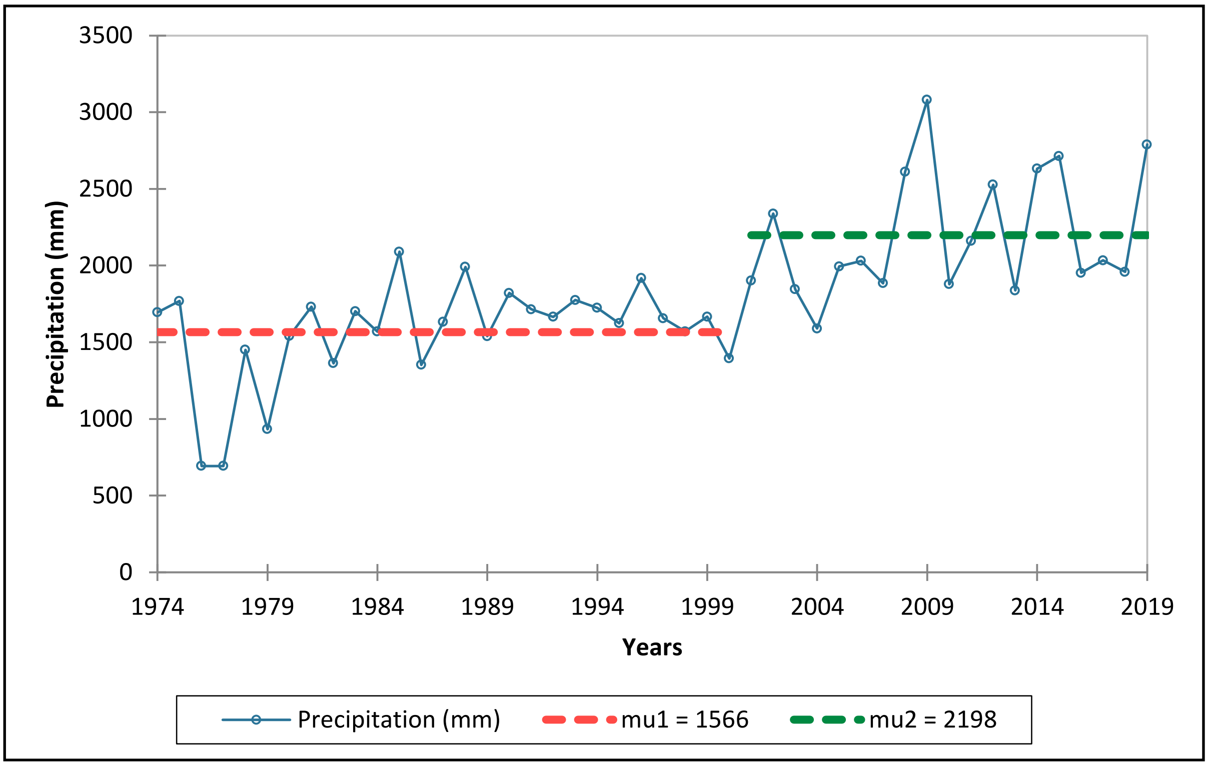

Figure 4. Rainfall pattern in Beni City (Pettitt and Buishand tests)

On the other hand, Hubert's segmentation (Table 5) allowed us to detect three periods of break (change in the mean) in the rainfall series between 1974 and 2019. Between 1974-1979, the average annual precipitation was 1205.7 mm compared to 1736.68 mm for the period 1980-2007 and 2348.01 mm for the period 2008-2019. The 2008-2019 period is therefore very wet compared to the other two previous periods. The rainfall deficit of the years 1974-1979 compared to the years 1980-2007 is 35.20 % while the rainfall deficit between 1980-2007 compared to the years 2008-2019 is 22.61% (Table 5).

Table 5. The significance level of Scheffé's test: 1% (Hubert's segmentation)

Start	End	Average (mm)	Standard deviation (mm)	Difference (mm)	Rainfall deficit (%)
1974	1979	1205.7	493.25	530.98	35.20
1980	2007	1736.68	228.28	611.33	22.61
2008	2019	2348.01	423.23	Reference	Reference

Rainfall Deficit for the Years 1970-1990

The rainfall deficit for the period 1974-1979 compared to the period 1980-2007 is 35.20% while the rainfall deficit for the period 1980-2007 compared to the period 2008-2019 is 22.61% (Table 5). These results are similar to the findings (Assemian et al., 2013) who found a break in tropical rainfall around 1968s. These authors show that this break is accompanied by a decrease in rainfall of about 19% on average and a 0.7°C increase in environmental temperature. This is therefore a climatic warming in this tropical environment that is characterized by two major periods: a wet period from 1920 to 1968 and a dry or deficit period from 1968 to 2005 (Assemian et al., 2013). Paturel et al. (2004) also locate the break detected by the Pettitt test and segmentation between 1964 and 1970 in tropical regions with a decrease in rainfall during this period (Paturel et al., 2004; Sultan et al., 2001). The rainfall deficit map of Paturel et al. (2004) for Africa shows a deficit of between 10 and 25% in the Cuvette Centrale regions, especially in the Ubangi basin and in the eastern part of the DRC from the Oriental Province (now Tshopo) with possible extensions to the Ituri and Beni regions (Paturel et al., 2004).

In contrast to Paturel et al. (2004), Rodier (1962) had already drawn up a map showing that the rainfall deficit had also affected the western part of the Congo Basin, especially towards the Kasai, towards the end of 1958. Rodier's (1962) conclusions are similar to those of Paturel et al. (2004) regarding the distribution of the rainfall deficit within the DRC: a deficit or surplus of 10% (-10% - 10%). Kalombo (1995) found that in southeastern DRC, the 1980-1994 period was marked by negative rainfall anomalies. This author reports that these anomalies were limited to the equatorial regions in the area located in the lower Shaba plateaus (present-day Katanga) and the rim of the Cuvette Centrale. What is noteworthy is that this study concludes that the rainfall anomalies in this area are of low intensity and do not seem to constitute a major climatic problem (Kalombo, 1995). These observations are similar to those obtained in this paper.

The conclusions of this paper on the City of Beni are similar to those of Ozer and Perrin (2014) who show, after applying the Pettitt test, two sub-series in West Africa: 1921-1967 and 1968-2007. These authors consider that the great drought ended in 1987 ($p=0.02$) and was followed by an increase in rainfall activity of around 17% from 1988 to 2007 (Ozer & Perrin, 2014). These authors thus note that very deficient years have not been observed since 1988. This observation is similar to the rainfall trend in the city of Beni (Table 3 and Figure 4), where it is also observed that from 1988 onwards the deficits are less significant than in the previous period. Results from a study conducted in the West Africa, East Africa, and Congo Basin regions show that complicated seasonality with sometimes several wet seasons that may or may not be distinct from each other complicates the detection of drought episodes in rainfall series (Cook & Vizy, 2019). This is similar to the situation observed in the city of Butembo where drought periods are not well-marked (Sahani et al., 2012). In this city located a little higher up compared to the city of Beni, Sahani et al. (2012) observed alternating dry periods between 1957 and 2010. However, the standardized Lamb index also shows a deficit around the years 1965-1969 and 1971-1974 in the Butembo time series (Sahani et al., 2012). This trend appears similar to the results of this study even though the rainfall data from the 1950s-60s in Beni town were not used. These data from before the 1970s could have allowed for a better comparison of periods. These results are all the more valid since, in the Central Congo Basin, the duration of the dry season varies with distance from the equator in both hemispheres and also according to a gradient from east to west (Asefi-Najafabady & Saatchi, 2013). In addition, the average monthly temperature hardly varies over the season (Asefi-Najafabady & Saatchi, 2013).

If we take the period from 1974 to 2000 compared to the period of 2000-2019, the significant deficit of precipitation with an increasing trend from the 2000s is noticed. The period from 1980-2007 is characterized by a deficit of 22.61% compared to the last decade (2008-2019) (Table 5). This trend is similar to that observed by Kouakou et al. (2007) in tropical regions between Côte d'Ivoire and Burkina Faso. Indeed, these authors report that climatic variability has led to alternating dry and wet periods and severe drought over the period 1970 - 2000 with immediate consequences on water resources in this tropical region. Indeed, the rainfall regime decreased from 14% to 31% and that of the rivers also decreased from 44% to 54% (Kouakou et al., 2007). Nevertheless, many research studies consider the period of 1970-1980 as the only one of great drought in the humid tropics (Taïbi et al., 2014) with a period more marked by the alteration of the rainfall regime in the two hemispheres around the 1980s (Olivry, 1994). Considering the period between 1925 and 1990 as a reference period, Paturel et al. (1998), reveal that the entire West and Central African region experienced three periods: (a) 1936-1950, a deficit period; (b) 1951-1968, a surplus period and (c) the period 1969 to 1998, a new deficit period (Paturel et al., 1998).

Rainfall Variability in Beni City

Figure 2 shows a fairly large variability in mean annual rainfall in Beni City. On the other hand, the intra-monthly variations are less significant. Despite the absence of temperature data, the analysis shows two seasons: the months of January-February and June-July with low rainfall (dry season), and the other months are well-watered (wet season) (Table 2). These are conclusions similar to those reported by many studies of the humid tropics.

According to Lebel & Vischel (2005), tropical regimes have two particularities that clearly distinguish them from those of the mid-latitudes: (i) their seasonal cycle is well marked and more stable (than that of the mid-latitudes) from one year to the next; (ii) rainfall is for the greater part of the year lower than potential evapotranspiration (PTE), particularly for semi-arid areas located in the subtropics. These two essential characteristics explain why, except in the immediate vicinity of the equator where the influence of the Intertropical Convergence Zone (ITCZ) is felt almost permanently, tropical regions are particularly sensitive to droughts, even though the total annual rainfall is often comparable to or greater than the total rainfall of temperate regions (Lebel & Vischel, 2005). These authors, like others, recognize two seasons on the one hand, the existence of one (or two) dry period(s) in the year each year and two rainy (wet) periods (Bweya et al., 2019; Kalombo, 1995; Lebel & Vischel, 2005; Sahani et al., 2012; Vyakuno, 2006). On the other hand, evaporative balances there are controlled by rainfall abundance, whereas in temperate zones they are rather controlled by temperatures (Lebel & Vischel, 2005).

Apart from these previously cited studies, the conclusions of Williams et al. (2012) explain rainfall variability by two mechanisms. First, the convergence of dry air over parts of East Africa and the Greater Horn of Africa reduces local convection and rainfall. It also produces a clockwise circulation response near the ground that reduces moisture transport from the Congo Basin (Williams et al., 2012). This first mechanism is also mentioned in the paper by Caminade & Terray (2010). Second, surface pressure gradients that draw moist air into East Africa and the Greater Horn of Africa from the tropical Atlantic Ocean and the Congo Basin. The strength of these gradients strongly influences total rainfall over East Africa and explains important phenomena such as the 1960-1980 rainfall decline and the devastating 1984 drought in the Great Horn of Africa (Williams et al., 2012).

Authors such as Sultan et al (2001) note that intertropical rainfall variability is linked to the Southern Oscillation (SO) on interannual and multi-year scales. One of the most important expressions of the AO is the El Niño-Southern Oscillation (ENSO) in the equatorial Pacific, which is defined as the dominant source of interannual and multiyear variability in the world (Sultan et al., 2001). Indeed, the phenomenon has a considerable systematic impact on temperature and precipitation fields, not only around the Pacific and Indian Oceans but also in the peri-Atlantic regions, as ENSO is associated with the variability of SSTs (Ocean Surface Temperature) and trade wind flows over the tropical Atlantic (Camberlin, 2007; Sultan et al.) Similarly, during the 1970-1988 droughts, near-global anomalies were observed in the tropical zone, corresponding to the ENSO phenomenon (Richard et al., 2001). However, Malhi & Wright (2004) believe that the relationship between ENSO and rainfall in tropical Africa appears to be less direct.

The results of Schreck & Semazzi (2004) also show the importance of the El Niño-Southern Oscillation (ENSO) phenomenon in the variability of rainfall in Eastern Africa (Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Uganda, and Tanzania). It is likely that the city of Beni located near Uganda (~486 km from the capital Kampala) was affected by ENSO. Indeed, ENSO is associated with higher than normal rainfall amounts during short rains throughout the region, with the exception of Sudan (Schreck & Semazzi, 2004). These authors indicate that the corresponding low-level anomalous circulation is dominated by eastward inflow from the Indian Ocean and, to a lesser extent, the Congo Rainforest, into the region of positive rainfall anomaly that extends over most of eastern Africa (Schreck & Semazzi, 2004). Indeed, the inflow from the east into East Africa is part of the outflow diffluent from the maritime continent during warm ENSO events. In addition to ENSO, Schreck & Semazzi (2004) found that rainfall variability over eastern Africa is associated with decadal variability (trend mode). Thus, these authors believe that, unlike ENSO, the trend mode is characterized by positive rainfall anomalies over the northern sector of East Africa and opposite conditions over the southern sector. This precipitation trend mode has not been detected in previous studies that did not include data from the last decades (Schreck & Semazzi, 2004). Projection of the wind on this mode indicates that the primary flow feeding the positive anomaly region over the northern part of East Africa emanates mainly from the southern region of East Africa and Sudan, where rainfall is insufficient. Although Schreck & Semazzi (2004) do not attribute the trend mode to global warming (partly due to the relatively short time period of the analysis), the evidence, based on their results and previous studies, strongly suggests a potential link to climate variability.

CONCLUSION

The objective of this paper was to date the 1970-1990 rainfall deficit in the tropical city of Beni. Trend and break tests were used to analyze the time series for the period 1974-2019. After analyzing the data, the results show that the total annual rainfall fluctuates greatly from one year to the next. Intra-monthly variations are less significant and inter-monthly variations reveal two seasons: a dry season in January-February and June-July and a wet season. The study reveals three break periods that could be qualified as indicators of change in the probability law of precipitation. The hypotheses formulated in the introduction of this article are verified.

Nevertheless, this study is subject to a limitation. Indeed, the use of rainfall data from a single meteorological station does not allow for a proper understanding of local variability in the region. However, in the context in which the study was conducted (absence of meteorological data, absence of drought data), the results can already serve as a basis not only for future research but also for other actors. Thus, based on the findings of this paper, it is suggested that public authorities fund projects to install climate equipment and collect data to better study local climate change. Understanding local climate variability will allow to propose adaptation strategies in the sectors most vulnerable to climate change such as water, agriculture, and livestock. In addition, future research should test the effectiveness of using satellite data from different databases to characterize the climate, which is still poorly known in the region. Satellite data is an opportunity for regions with low density of weather stations.

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