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Temporal Climate Variability in Luki Biosphere Reserve, Mayombe, Democratic Republic of Congo

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Abstract:

The aim of this study was to evaluate the temporal climate variability in Biosphere Reserve of Luki (BRL) in the Democratic Republic of Congo (DRC) from 1959 to 2018. Historical weather data (total daily rainfall, average daily temperature, and average daily relative humidity) collected at Luki meteorology station were analyzed using the Standardized precipitation index (SPI) method. All weather data series used were homogeneous. Results indicated a significant increase in temperature over the reference period and slight increase in both precipitation and relative humidity. A decrease in the number of rainfall days was also observed. The SPI values pointed to higher climate instability of the Luki biosphere. Rainfall onset was observed in the month of October with a drift at the beginning of November and retreated in May. The dry season spanned over a period of 5 months on average. The high climate variability observed at this meteorological station confirm that DRC and probably other Central African countries may not be immune to climatic change. In such environments, development of climate-smart technologies such as early maturing crop varieties and the use of sustainable agricultural practices such as mixed cropping and agroforestry is recommended especially to small farmers to increase resilience and adaptation to climate change.

Keywords: Climate-Smart Agriculture; Climate change; Global warming; Cropping calendar; Seasonal characteristics

1. Introduction

The notion of climate variability, which merges with that of climate change, designates the modification of the climate on the scale of human life caused by anthropogenic or natural effects [1-2].

This definition has the advantage of simplifying the one given by the Climate Convention and considering the IPCC definition which considers climate change as a long-term anthropogenic or natural variation of the climate [3]. The manifestations of this climate change depend on the countries and regions.

In West and Sahelian Africa, several studies have been carried out to understand and document the impact of climate variability [1,4-6]. They all project mixed results with some models predicting a reduction in yield of certain crops while other models predict an increase in crop yield by the year 2050. For instance, the yield for finger millet (*Eleusine coracana* Gaertn) and sorghum (*Sorghum bicolor* (L.) Moench), has been predicted to decrease by 15 to 25%, irrigated rice would increase by 10 to 25% and rainfed rice would increase by 2 to 10% [3]. In East and Central Africa, reduced agricultural productivity, deterioration of water quality and quantity, and loss of biodiversity have been projected as the main impacts of climate variability [3].

The geographical position of Central Africa in the heart of a continent extending on both sides of the equator, makes it insensitive to the modulations of large-scale circulations; the surface conditions in which the continuous forest cover contributes to the maintenance of high humidity in the lower layers and the instability of the air mass, make Central Africa in general and the Congo Basin less affected by climate variability [3].

Indeed, there is an increasing influx of scientific work on the analysis of climate variability in Central Africa [7-10], while the unavailability of data and the rainy climate context did not arouse as much interest until recently [3]. This testifies to the efforts made to make scientific data available and to the awareness of the actors of the danger that awaits this part of the world if we do not plan and act.

The maintenance of forest cover, which seems to be more decisive in climate stability, would largely depend on the awareness of the local population of the harmful effects of climate change. Thus, the IPCC report [11] confirms with certainty the primacy of human responsibility in climate change.

The African continent in general loses about 4 million hectares of forest per year, i.e. a deforestation rate of 0.8% [12]. In the Democratic Republic of Congo, this rate varied from 0.22 to 0.25% between 2000 and 2010 [13]. According to these authors, the projections for 2035 indicated higher values due to the trend of increasing demand for arable land and the farming methods used.

In Mayumbe, more than 100,000 inhabitants located inside and around the Luki Biosphere Reserve use slash-and-burn agriculture, carbonization, cutting firewood, hunting and then sawing wood to survive [14]. These activities, which have had a considerable impact on the integrity of the forest, have led to the loss of more than 12% of its forest cover between 2010 and 2018, the record of which was obtained in 2014 with more than 1,500 hectares lossed [15]. This rate of deforestation is at the same time having a negative impact on the climatic evolution of the Luki Biosphere Reserve, which has implications to local resident's agricultural activity and the conservation of biodiversity. Knowing the current state of climate in Luki Biosphere Reserve would serve as a benchmark for all the actors working in the area to make more effective the adaptation and resilience implemented policies.

This study aims to provide knowledge on the current state of the climate of the Luki Biosphere Reserve through the analysis of a long time series from 1959 to 2018.2.

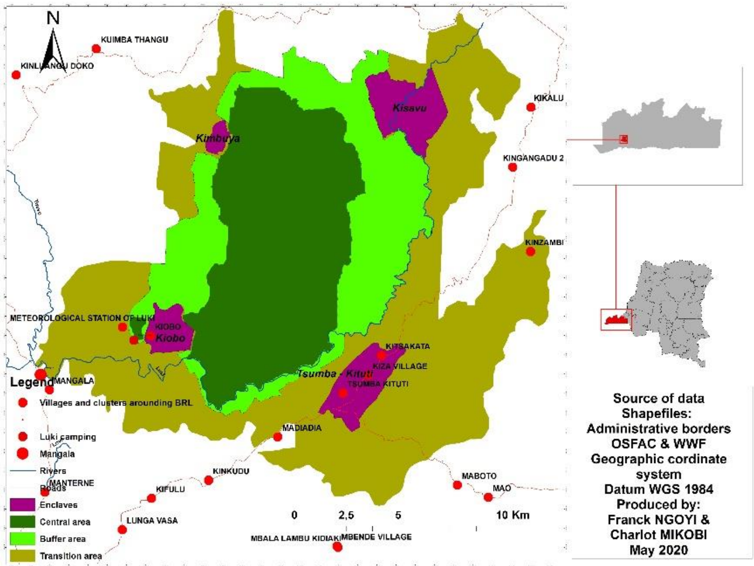
2. Materials and Methods

2.1. Study site

The Luki Biosphere Reserve was established on January 12, 1937 by the Governor General of the Belgian Congo colony. This territory was part of the wooded domain of the State. Its management was entrusted to the National Institute for the Agronomic Study of the Belgian Congo (INEAC) and is now ensured by a local steering committee (CLP) composed of: INERA, president; M.A.B vice presidency, the representative of National NGOs working in and around the reserve, the representative of donors (ERAIFT), the representative of customary chiefs, the representative of the governor [16]. It has been recognized since 1979 as a Biosphere Reserve by UNESCO [17].

The Luki Biosphere Reserve is located in the South-West of the DRC (latitudes between 05°35' and 05°43' South, longitudes between 13°10' and 13°15' East), in the province of Kongo Central 120 km from the Atlantic coast [17,18]. Organized into three zones (central, transition and buffer zone), it covers an area of just over 33,000 ha (Figure 1) and is crossed almost entirely by the Luki River watershed [17]. The soils are generally ferralitic, acidic with a low cation content [19]. The relief consists of a series of hills whose altitude varies between 300 and 500 m [21]. The vegetation is very varied depending on whether it grows on hydromorphic soils or on young land and according to the forms of the biotopes (bottoms of valleys, savannahs, edges, dense forests, rivers, clearings, fields) [21].

The climate is the humid tropical type Aw5 of the Köppen classification [22], influenced by the cold sea current of Bengwela and the south-east trade winds due to the proximity to the Atlantic coast [23]. A small dry season of low amplitude is sometimes noticeable between December and February [18]. The rainy season extends between October and May and the long dry season between June and August, sometimes September [18]. Interventional studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.



Source of data
Shapefiles:
Administrative borders
OSFAC & WWF
Geographic cordinate
system
Datum WGS 1984
Produced by:
Franck NGOYI &
Charlot MIKOBI
May 2020

Figure1: Study site

2.2. Historical weather data

The Luki Reserve has had an operational climatological station since 1948. The study data, which was recorded daily by the observers manually at 6 a.m., 9 a.m., 12 p.m., 3 p.m. and 6 p.m. in the notebooks and daily observations and kept at the climatology office of the RBL are (i) the sum of daily precipitation (Pj); (ii) the average daily temperature (Tj), and; (iii) the average daily relative humidities (HRd) covering the period from 1959 to 2018 used in this study were entered in Excel.

2.3. Historical weather data analysis

Precipitation, air temperature and relative humidity were analyzed using descriptive statistics using average values, figures and graphical representations. To assess the evolution of precipitation during the study period, the method of standardized precipitation index (SPI) created by MCKEE et al. [24], approved during the leave of the World Meteorological Organization of 2011 and applied by Tshiabukole et al., [8] was used. This index is based on the probability of precipitation for a given time scale. Developed by Keyantash and NCARS, [25], the SPI allows the monitoring and evaluation of meteorological droughts caused by a lack of precipitation. SPI<0 indicates deficit and dry periods while SPI > 0 indicates excess and wet periods [25,26]. SPI is calculated as follows [8,27].

$$SPI = \frac{Pi - Pm}{S}$$

Where Pi=the rain of month or year, i= Pm: the average rainfall of the series on the time scale considered; S= the standard deviation of the series on the time scale considered

2.3.1 Length of rainy season and number of rainy days

The determination of the dates of the start and end of the rainy season was made by the method of Stern et al. [28] which is applicable in humid areas [29]. According to these authors, there is a start of the rainy season when 20 mm of rain is collected in two consecutive days without a dry period of more than ten days in the thirty days that follow. The end of the rainy season is noted when there is no more rain for a period of fifteen days. Are considered as rainy days those whose cumulative precipitation is ≥ 1 mm, this would avoid the biases that could be induced by possible variations in the consideration of light rains [30].

2.3.2 Numbers of dry months

The method of Bagnouls and Gaussen [31] was used to determine the number of dry months. According to this method, a month is said to be dry when the average precipitation, expressed in millimeters (mm), is less than twice the temperature, expressed in degrees Celsius (°C).

2.3.3 Statistical analysis of data

Excel was used for data entry and XLSTAT software was used for the statistical analysis of the historical weather data. Descriptive statistics (mean, standard deviation, coefficient of variation, Pearson correlation), tables and figures were generated.

3. Results

3.1. Variation in rainfall, temperature, and relative humidity in the Luki biosphere reserve (1959-2018)

3.1.1. Rainfall

The average monthly precipitation values in the Luki Biosphere Reserve from 1959 to 2018 are presented in Table 1. The values varied from 234.1 mm in December to 1.6 mm in July. The small dry season which often occurred at the beginning of January tends to disappear. The sum of precipitation is 531.4 mm in season A and 833.6 mm in season B. The months of April and December remained the rainiest with 233.1 mm and 234.1 mm respectively.

Table 1: Average monthly precipitation

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	198.4	209.3	107.6	233.1	85.2	4.5	1.6	6.2	19.4	165.6	131.7	234.1

Annual rainfall values hovered around the mean (Figure 2). The interannual variability is not too great, but it is worth pointing out the above-average values in the period between 1959 and 1963. The period from 1964 to 1997 is characterized by the dominance of precipitation values below the annual average. The period between 1998 and 2018 showed a balance between values below and above the average. 2011 was a year of heavy rains.

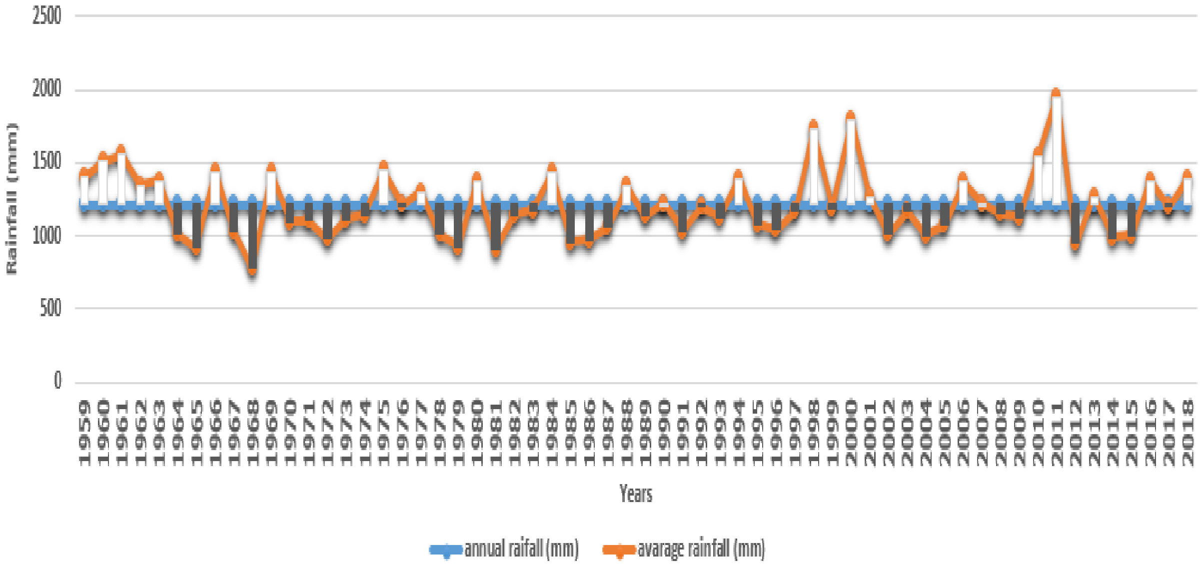


Figure2: Variation of annual precipitation in the Luki Biosphere Reserve

There is a gradual downward trend in the Standardized Precipitation Index (SPI) values (R^2= 0.036). The years 1998, 2000 and 2011 were the wettest in the series. On the other hand, the years 2001 and 2013, which recorded very low values of SPI, were drier (Figure 3). A longer drought was recorded in 2001 and 2017. The series analyzed is globally in deficit (58.4% of the years).

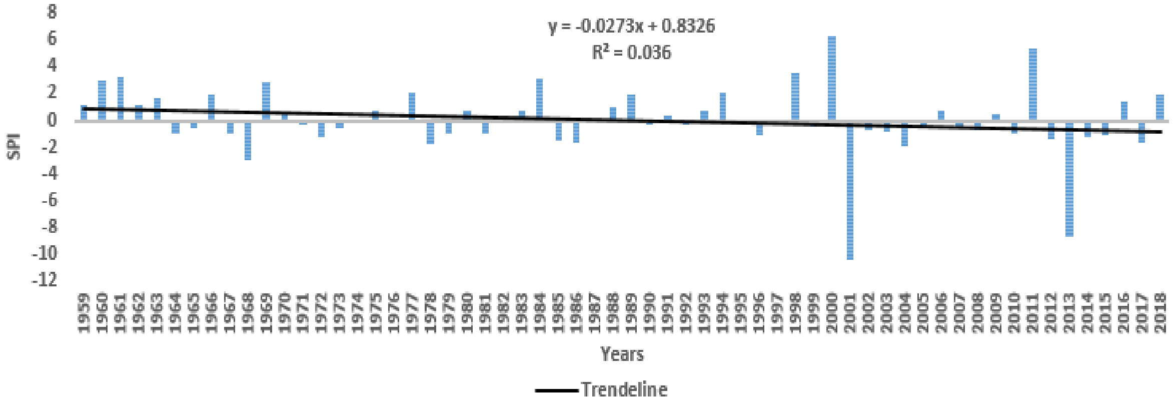


Figure 3: Standardized Precipitation Index (ISP)

In the Luki Biosphere Reserve, October is the month of rainy season begin (65%), followed by November (23.3%), December (6.7%) and September (5%) (Figure 6). The end of the rainy season was observed in the first half of May (92%) followed by June (8%) (Figure 6). Overall, a tendency to shift the start of the rainy season towards the end of October and even the beginning of the first half of November is observed (Figure 4).

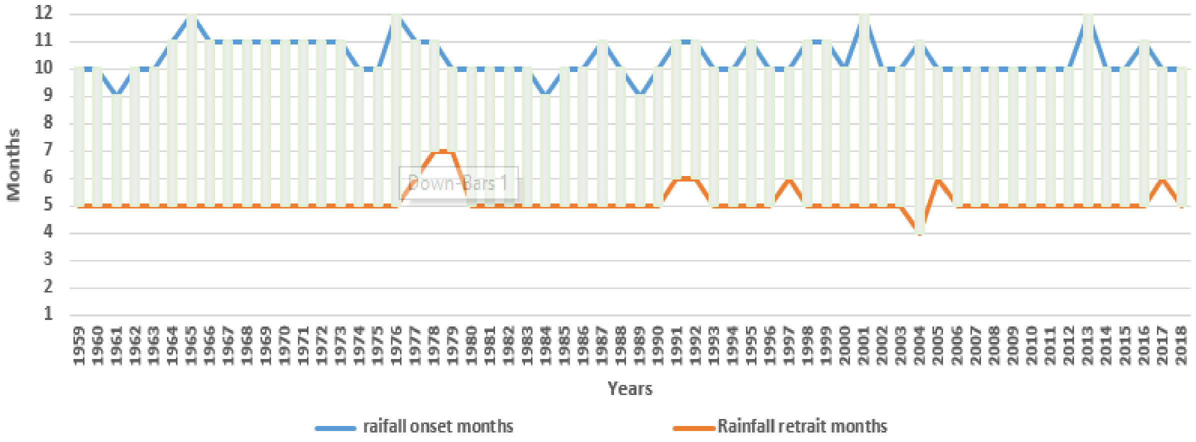


Figure 4: onset and retreat rainy season over the period covering 1959 to 2018.

According to the results obtained, the Luki Biosphere Reserve is mainly characterized by 5 months of dry season (Figure 5). The month of October becomes increasingly dry from the 1964 year, the decade of the beginning of the fall in rainfall and clearly indicates the instability of the climate of Luki. The dry season which begins in May and ends in September tends to extend towards the end of October and even the beginning of November, engulfing 15 to 30 rainy days. The small dry season is unstable and occurs in December, January, February and even early March. November and April are the rainiest months. March and April are the hottest months. August remains the coldest month with an average temperature of 25°C. Figure 8 below presents the average ombrothermic diagram of the study area.

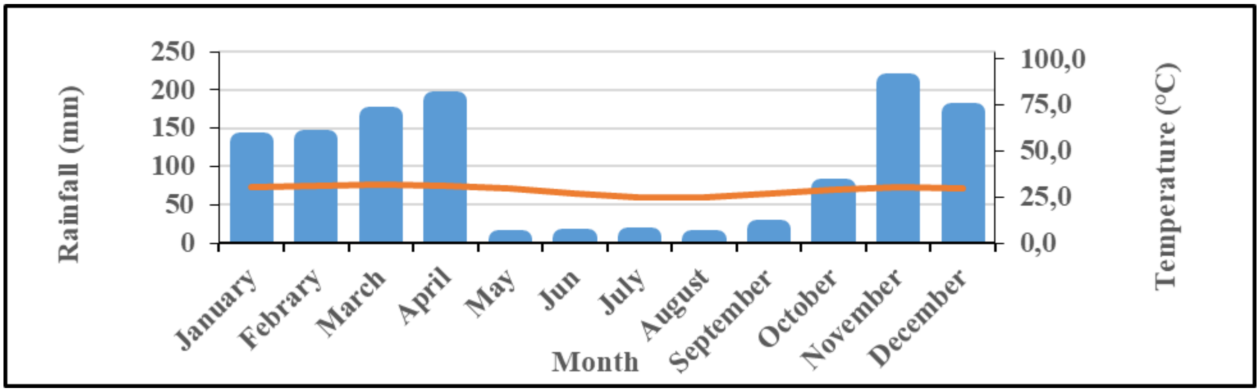


Figure 5: Luki's ombrothermic diagram

3.1.2 Temperature

The average air temperature values for the period 1959-2018 in the Luki Biosphere Reserve are recorded in Table 2 below. They vary between 21.1°C (August) and 26.8°C (February). February is the hottest month followed by April. August is the coldest month followed by July.

Table 2: Monthly mean air temperature at Luki station (1959-2018)

Months	Janv	Febr	Mar	April	May	Jun	July	Aug	Sep	Oct	No	Dec
Temp (°C)	26.0	26.8	26.2	26.6	25.7	23.8	22.3	21.2	23.0	25.4	26.3	26.1

The annual temperature trend line in Luki Biosphere Reserve (Figure 4). Two major periods emerge: from 1959 to 1984, the annual temperature values are below the average value. The very low values were reached in 1980. The opposite situation occurs in the period between 1985 and 2018 with the record high value in 2016.

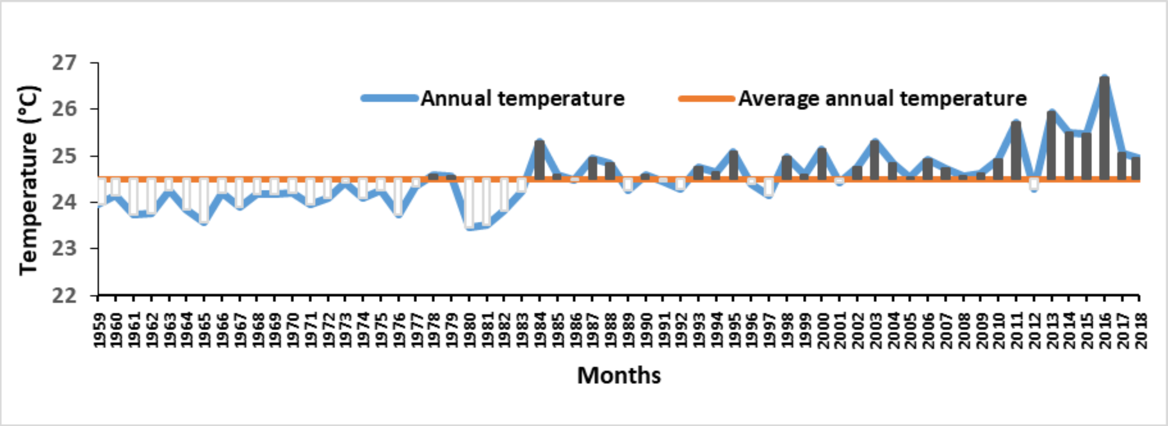


Figure 4: Interannual temperature variation

3.1.3 Relative humidity

The monthly relative humidity varied from 68.6 in October to 74.3 in May. (Table 3).

Table 3: Monthly mean value of relative humidity

Months	Jan	Febr	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Relative humidity(%)	72.4	71.9	70.7	72.4	74.3	73.3	72.1	71.8	70.8	68.6	70.2	72.5

Annual relative humidity values are mostly below average (Figure 5). All the same, three major periods emerge: the period from 1959 to 1962, the period from 1963 to 2015 and that from 2016 to 2018. The first period and the third are characterized by relative humidity values higher than the annual average. The third presents very high peaks and a clear upward trend. The second period is that of humidity fluctuation between positive and negative values.

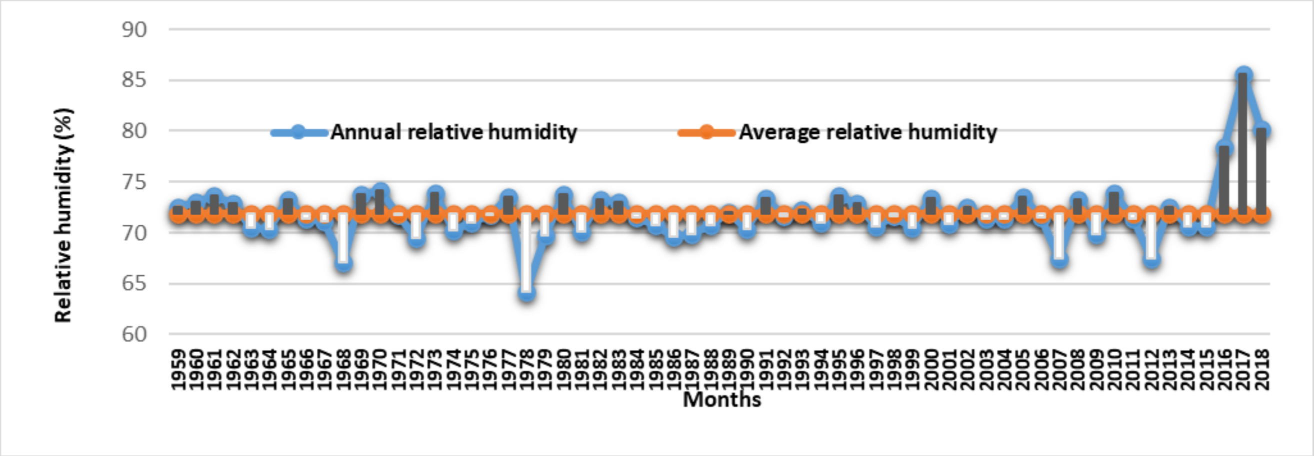


Figure 5: Interannual variation in relative humidity

3.2 Relationship between Temperature, Rainfall and Relative humidity

Descriptive statistics (means, standard deviations, coefficient of variation) of the variables analyzed are presented in Table 4. The coefficients of variation for the three parameters are below 20% implying that the series studied were homogeneous.

Table 4: Descriptive statistics of precipitation, temperature and relative humidity

Variables	Mean	Standar deviation	Coefficient of variation (%)
Average precipitation (mm)	1211.8	228.875	18.888
Average temperature (°C)	24.535	0.607	2.4522
Relative humidity (%)	71.955	2.966	4.1271

Table 5 below shows that the variables analyzed are not strongly correlated with each other. A very weak correlation is observed.

Table 5: Pearson Correlation Matrix

	Rainfall	Temperature	Relative humidity	Rainfall days
Rainfall	1			
Temperature	0.2424	1		
Relative humidity	0.2845	0.2037	1	
Rainfall days	0.4223	0.0043	0.3442	1

4. Discussion

The climatic data collected since 1959 in the Luki Biosphere Reserve constitute a scientific heritage of considerable importance for the assessment of climatic variation in the region. The results obtained in this study demonstrate, for the first time in DRC, the evolution of climate variability over the last six decades and a significant increase in the average annual temperature whose values are below the average in the period between 1959-1984 and above average in the period between 1985-2018. Statistical data show that precipitation and relative humidity values have remained relatively stable over the past 60 years.

Our findings are in line with other authors who reported a no significant variation in rainfall in the Congo basin and an increase in temperature in central Africa, Congo Basin, Benin, Burkina Faso, DRC [6, 7, 32, 33]. The appearance of heavy rains would be due to the El Nino phenomenon while the deficit rains would be attributed to La Nina [7]. The series studied provides information on a strong interannual temporal variability of precipitation, causing rainfall breaks. This water deficit would have an impact on agricultural activity. Without errors due to manipulation of materials and modification of the immediate environment, the interannual average can vary for many reasons, among which the effects of climatic variability occurring during the observation period [29]. Dekoula et al. [34] noted that the variability of climatological parameters is a function of altitude. Quénol [30] attributes it to the influence of local characteristics such as topography or various obstacles in the environment.

This study observed reduced precipitation in the 1960s and 1970s and this agrees with several authors [3,5,33-35]. According to these authors, these results influenced the seasonal dynamics of rainfall, thus modifying the rainfall balance previously established between season A and season B. A normal resumption of rainfall was observed from the end of the 1980s. Assani [36] noted that the 1980s marked the beginning of the decrease in rainfall in Lubumbashi, DRC. In West Africa and the Sahel, the decrease in rainfall was observed from the end of the 1960s with an intensification from the 1990s and 2000s [2,29,37].

The temperature increases of +0.9°C found in the Luki Biosphere Reserve between 1959 and 2018 is a lower value than the continental average of 1.2°C [38] and corresponds to the projection of climate change at the regional scale produced by regional models [32]. In the center of INERA M'VUAZI, Kabongo [8] found the same trend with a temperature increase of 1°C in the period between 1962 and 2012. In humid tropical areas such as Luki, the increase in temperature is relatively low and would be influenced by the presence of dense humid forest [32].

Much of the study period falls within the range of 1960 to 2000, which corresponds to the era when one-fifth of the world's tropical forest was razed, and which would have led to intense heat waves [30]. The 2010, 2015, 2016 and 2018 years, have been warmer on the African continent since 1950 with an increase of 1.4°C, 1.2°C, 1.3°C and 1.1°C respectively [38]. The increase in temperature observed in this study is consistent with all the projections of the major studies made on the modeling of the climate situation in Africa and in the world ([12,38,39].

The relative humidity values found are characteristic of more humid air (RH ≥ 65%) which characterizes the area of the Luki Biosphere Reserve [40]. The lack of large variations in this variable observed in this study would be due to the mists witch fall during the dry season and which compensate the water deficits [16].

The high climatic variability observed in the Congo Basin [5] and West Africa [4] affect the planning of agricultural activities and a positive correlation between rainfall onset date and the date of sowing of millet has been reported for southwestern Niger [37]. Our results of reduced number of rainy days are also in agreement with the findings by Couralet et al. [18] who observed that onset and cessation of rains was in the Luki Biosphere Reserve between 1948 and 1957 in the months of October and May, respectively.

Sahani et al. [10] also reported a reduction in the number of rain days in Butembo in the eastern DRC. Seasonal rainfall breaks or droughts are harmful to the emergence, vegetative and reproductive phases of many crops and constitute a major climatic risk [42]. The lack of water on the rice crop in the flowering phase, for ex-ample, leads to the production of empty grains.

Excessive rainfall often interferes with the harvesting, drying and storage of especially cereal grain crops resulting into higher post-harvest losses. So, proper planning of agricultural activities needs to be informed by weather advisories.

Results of the current study met the Köppen classification under the AW category which is characterized by among other things, the average temperature of the coldest month being above 18°C and the rainfall of the driest month being above 60 mm (Dubreuil et al., 2017).

Conclusion

The study of the temporal climatic variability in the RBL highlighted the instability of the climate with the rainfall onset increasingly late. There is a trend towards a significant increase in temperature and a decrease in the number of rainy days. These fluctuations testify the climatic instability in the Luki Biosphere Reserve which requires special attention and leads to the conclusion that even if it is forested, the Congo Basin is not immune to climatic imbalances.

Agriculture being the main activity that greatly contributes to the survival of residents, this climatic disturbance could have negative impacts on agricultural production and household health. Thus, studies linking climate variability and agricultural activity should be implemented to serve as a basis for the reassessment of the agricultural calendar which is no longer appropriated. For more efficiency, the extension of this study to spatial data using additional surrounding climatological stations including modeling is essential. Intensifying activities for adaptation and mitigation to climate change such as agroecological practices to meet the food demand of exponentially growing populations and to preserve the natural resources of the reserve would be a conciliatory approach.

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Conflict of interest

The authors declare that there is no conflict of interest in the publication of this article.

Contribution authors

Franck NGOYI Tshite conceived the subject, collected data and analyzed it statistically, wrote manuscript; Alain Kaka di Makwala collected data; Ludivine Lassois, Bhely Angoboy Ilondea and Jean Pierre Kabongo Tshiabukole gave technical orientations and edited the manuscript, Ernestine Lonpi Tipi, , Joshua Okonya, Moses Odeke, Enock Warinda, Raoul Sambieni, Charlot Mikobi Mikobi, Daniel Dibwe Munkamba, André Nzomono Nsitu, Baudouin Michel, Roger Ntoto M'vubu, Joseph Lumande Kasali, Justin Mudibu wa kabangu and Alexix Ndayiragije edited the manuscript.

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