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RESEARCH ARTICLE

CONTRIBUTION TO THE STUDY OF ASSESSING RAINFALL PATTERNS AS INDICATORS OF CLIMATE CHANGE: A STUDY IN KINSHASA CITY, DEMOCRATIC REPUBLIC OF CONGO

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ABSTRACT

Climate change is manifesting globally with phenomena like floods, storms, crop failures, droughts, and migrations. Kinshasa, the capital of the Democratic Republic of Congo (DRC), is significantly impacted by these changes. Despite its vulnerability, modern research on climate change in the region is lacking. This study aims to fill this gap by investigating rainfall data as an indicator of climate change in Kinshasa. Analyzing 32 years of daily rainfall records (1988-2019), it evaluates patterns such as consecutive dry days, rainy season duration, and maximum daily rainfall. This comprehensive assessment seeks to enhance understanding of climate dynamics in Kinshasa and support the development of targeted resilience measures in the DRC

KEYWORDS

Rainfall, indicator, climate Change, episodes, frequency analysis

1. INTRODUCTION

Climate change is an increasingly evident reality, with profound implications globally (McKitrick, 2001; GIEC, 2008; Smith et al., 2009). Scientific studies have shown that economic activity has contributed to an increase in global temperatures and the occurrence of extreme weather events (Beniston, 2012; Ciarli and Savona, 2019; Fan et al., 2023). The burning of fossil fuels and changes in land use, such as agriculture and deforestation, have led to an increase in greenhouse gas concentrations in the atmosphere, resulting in more energy staying in the global climate system (Kohnert, 2024; Udall and McCabe, 2013). According to the latest report of the Intergovernmental Panel on Climate Change (IPCC), the impacts and consequences of this change on the water cycle mainly concern: The increase in temperatures since the middle of the 19th century, the modification of the average and the geographical distribution of precipitation with significant disparities at the regional level, the resurgence of periods of drought and heavy precipitation, aquatic ecosystems, and other water-related sectors including energy, food, and health (Mimikou et al., 1991; Leavesley, 1994; IPCC, 2011; Murray and Ebi, 2012; Bunel et al., 2023).

Kinshasa, the capital of the Democratic Republic of Congo, faces complex problems due to climate change (Kang et al, 2023). The city's hot and humid tropical climate exacerbates the main challenges due to the interaction of multiple stresses at various levels and the low adaptive capacity of populations (Lebailly and Muteba, 2011; Doherty et al., 2023; Shuku Onemba., 2011; ICREDES, 2017; Oxford Analytica, 2022). Among the challenges that Kinshasa is facing are:

- Rapid population growth, (5%) whose population is estimated at nearly 10 million inhabitants in 2016, and is projected to be between 14 and 17 million in 2030.
- Anarchic land use and Significant erosion phenomena.
- Unauthorized dumping of solid waste, often along the banks of rivers.
- Degradation of the quality of groundwater and surface water.
- Increase in periods of drought and heavy rainfall.
- Increase in temperatures since 2005.
- Modification of the average and the geographical distribution of precipitation with significant disparities at the regional level.
- Low water supply rate of 64% (Water demand: 950,000 m3 / d, Production: 550,000 m3 / d, Deficit: 400,000 m3 / d).

Nowadays, we are already witnessing increases in temperatures and disturbances in the seasonal Recent observations in Kinshasa indicate rising temperatures and disruptions in the seasonal and daily distribution of rainfall, leading to a shortened rainy season and an extended drought period. If climate change were to be evidenced through changes in rainfall, the chronological evolution of daily rains would be a critical indicator,

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especially in terms of annual precipitation patterns. This study aims to identify various indicators of climate change in Kinshasa based on detailed analyses of rainfall and temperature data.

2. MATERIAL AND METHODS

2.1 Study site

Kinshasa city extends has an area of 9965 km²(3847 mi²), along the southern shore of the "Pool Malebo" and constitutes a huge crescent covering a low flat surface with an average altitude of around 300m (see in figure 1). Kinshasa is Located between 4°17′30′′ and 4°30′00′′ latitude south and 15°12′ and 15°30′ longitude east. It is bound north and west by the Congo River, which is also the natural border with the Republic of Congo (Brazzaville), east and northeast by the Mai-Ndombe, Kwilu and Kwango Provinces, and south by the Kongo Central Province (Lateef et al., 2010; Kayembe Wa Kayembe et al., 2012; ICREDES, 2017; Lohaka et al., 2022). According to a few studies, the climate of the region is hot and humid tropical with two principal seasons: a rainy season from late September to May with warm temperatures (25.6°C) and a dry season that extends from June to September with slightly cooler temperatures (22.8°C) (Robert, 1946; Devroey and Vanderlinden, 1951; Makanzu Imwangana, 2010; and Lenzo et al., 2020). The average annual rainfall is around 1529 mm (60 in.) and the average annual temperature is 24 °C (Bultot., 1971). The monthly absolute maximum temperatures exceed 35 °C. Relative humidity is over 70% (between 71% minimum and 84% or higher maximum). Its annual average calculated over 24 hours is 81%: it fluctuates from 76% during the day to 86% at night. The average annual water balance of the soil calculated in relation to precipitation is 1362 mm (Lokakao and Shamba, 2016). It becomes loss-making in the course of June. Soil moisture reaches its maximum holding capacity (200 mm) at the end of October (Makanzu Imwangana et al., 2015). From a relief point of view, Kinshasa city is built on a contrasting topographical site, because it is both comfortable (the plain: the lower town) and restrictive (the hills: the upper town). Its geomorphology is formed by a continental shelf in the east, a chain of steep hills in the south, a plain and swamps on the edge of Congo River. The shelf is part of Kwango Shelf massif, the portion of which is located in the City of Kinshasa is called "Bateke Shelf ". Kinshasa Plain lies along the Congo River and is enclosed between Congo River and the foothills of the hills in a crescent shape (Mathieu, 1912; Lokakao and Shamba, 2016).

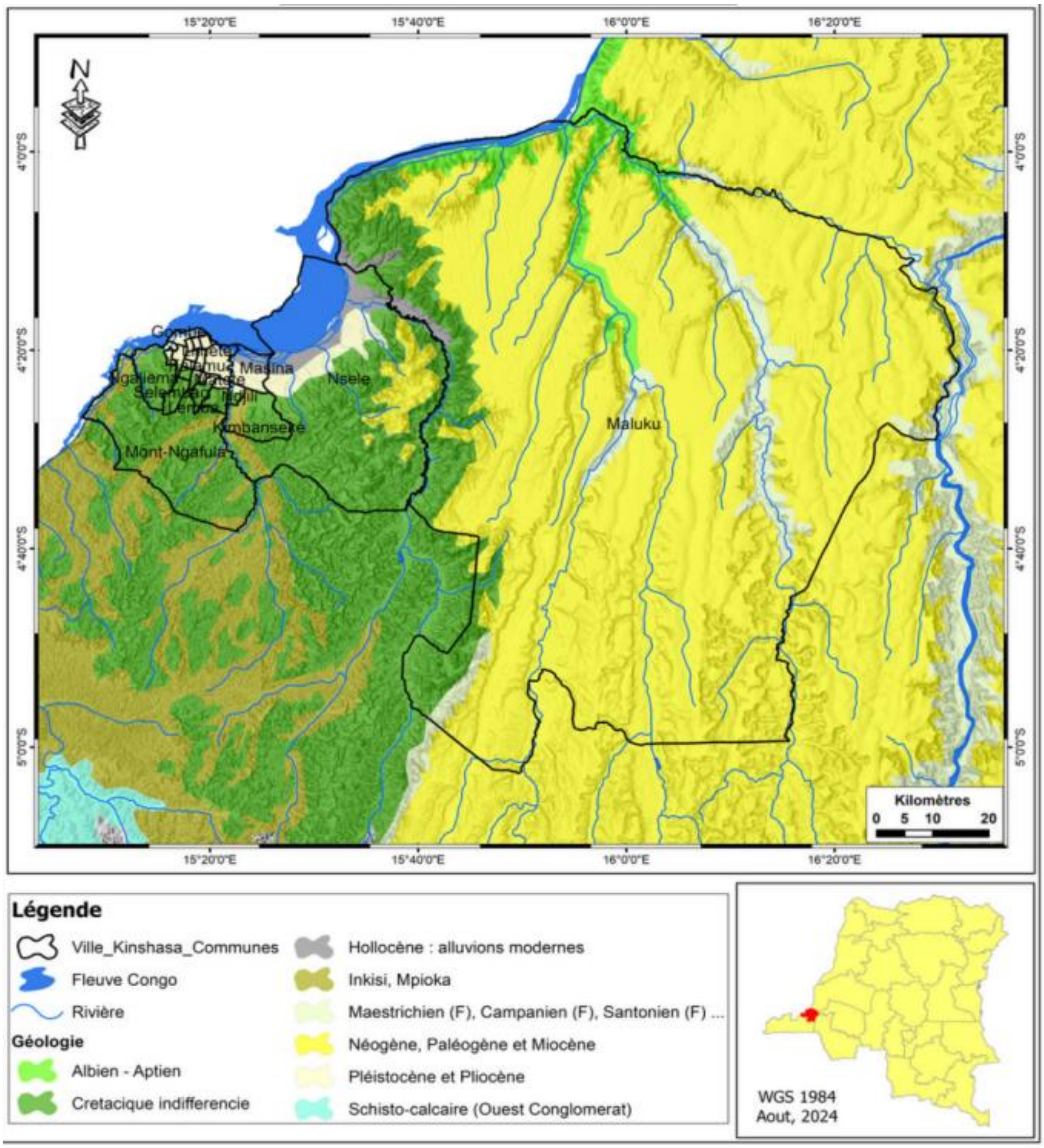

Figure 1: Location and geological map of the study area

Hydrographically, Kinshasa city is drained by rivers, the most important of which are the N'djili and the N'sele. Rivers such as N'djili, N'sele, Gombe, Funa, Basoko and Ndolo flow into the Congo River and play an important role in the city's transfer and supply, as depicted in Figure 2. The hydrographic basins are: Lubudi, Binza, Mampunza, Makelekele, Yolo, Matete, Bandalungua, Tshangu, Kalamu and Tshenke which have seasonally varying flows (Van Caillie,1983; Lepersonne, 1937; Ntombi and Tumwaka, 2004; Lumbi, 2013).

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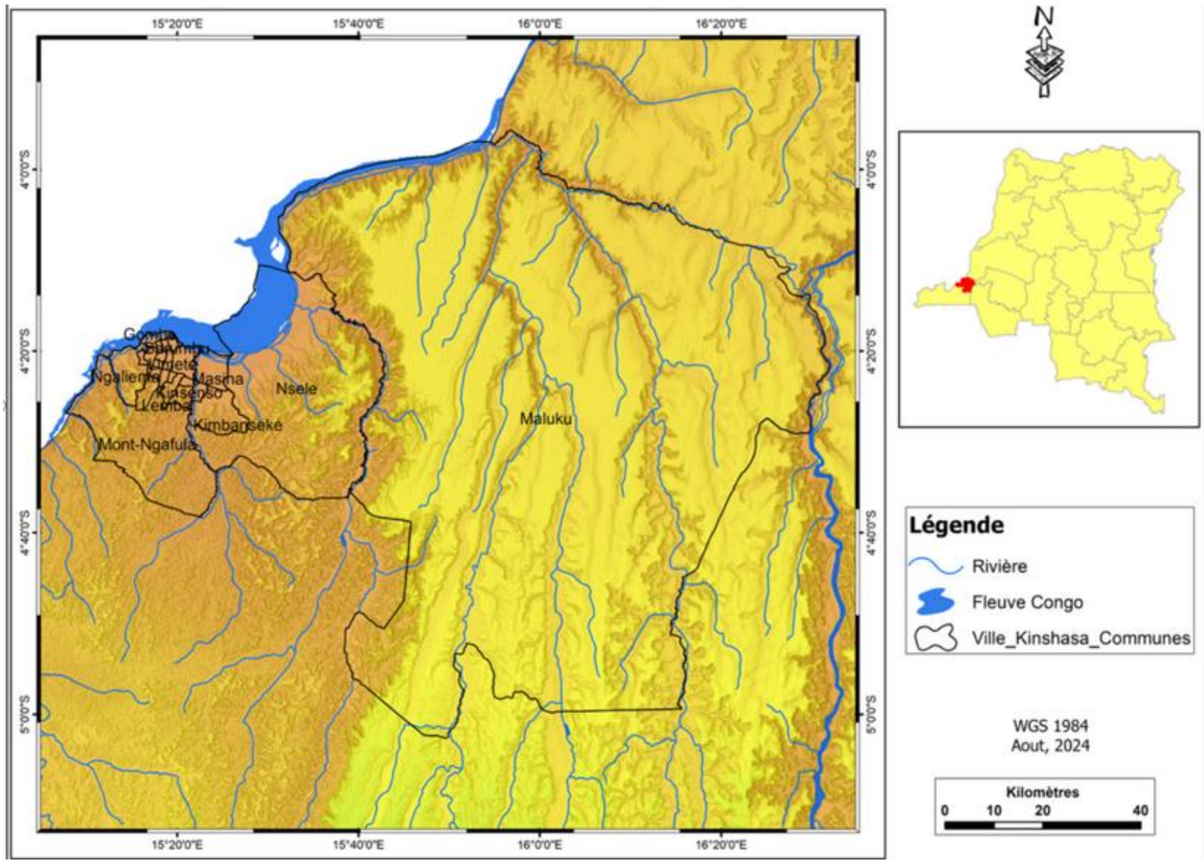

Figure 2: Hydrological map of the study area

The soil of Kinshasa is of the Arenoferrasol type, made up of fine sands with a clay content generally less than 20%. They are characterized by low organic matter content and a low degree of saturation of the absorbent complex (ICREDES, 2017). The basement is characterized by a Precambrian basement. This consists of finely stratified and often feldspathic red sandstone rocks. It constitutes the upper part of the Schistogresous System and outcrops at the level of the rapids at the foot of Mount Ngaliema and to the south of the N'djili River. This condensed rock is resistant to erosive action (Makanzu Imwangana et al., 2015).

Kinshasa region has a natural vegetation consisting of dry dense forests, savannahs, semi-aquatic, and aquatic formations in the valleys and around the Malebo Pool as noted by (Kikufi and Lukoki, 2008; Pain, 1984). However, In the town of Kinshasa, nothing is left of this luxuriant vegetation besides a few grasses like Laudetia demeusi and Schyzochysium semiberle (Tshibangu et al., 1997).

2.2 Meteorological data

The study utilized data on precipitation and temperature patterns observed over a period of thirty years, ranging from 1989 to 2020 in Kinshasa city, obtained from the Meteorological and Remote Sensing Agency by Satellite, also known as "METTELSAT," which serves as the national meteorological reference station. Through a comprehensive analysis of rainfall and thermometric trends, the study was able to evaluate the impact of climate change in the province of Kinshasa.

2.2.1 Rainfall data analysis method

2.2.1.1 Chronological analysis of daily rainfall

This analysis aims to observe any changes in the daily rainfall variable over the years and identify any consistent and non-random variation in either its volume or distribution over time. The chronology analysis can also focus on the daily distribution of rainfall, monthly, seasonal, or annual rainfall. For instance, it can examine the frequency of consecutive days without rain or the duration of the dry season (Kasongo-Numbi, 2008).

2.2.1.2 Frequency analysis of the random variable annual rainfall

Frequency analysis is a statistical method that predicts future occurrences based on past events using a frequency model (Kasuwa, 2012; Hansen, 2023; Baghel et al., 2019). This method involves the use of a frequency model, which is an equation that describes the statistical behavior of a process (Renard and Lall, 2014; Maity, 2022). These models provide the probability that the events studied will not be exceeded (Naghettini and Pinto, 2017). Climate change causes the dry module to return more frequently than the wet module (Papalexiou and Koutsoyiannis, 2012; Mishra et al., 2011).

The validity of frequency analysis results, including the probability of not exceeding a certain value and its recurrences, depends on the choice of the type of frequency model. While various methods can aid in selecting an appropriate frequency model, unfortunately, no universal or infallible approach can guarantee optimal results in all cases (Papalexiou and Koutsoyiannis, 2012; Font et al., 2013; Kasongo-Numbi, 2008; Panahi et al., 2021).

The maximum rainfall or daily flow would be better described by Gumbel's distribution since the annual rains in the intertropical zone usually conform to the normal law (Bacharou et al., 2013; Ciupak et al., 2021;Rozos., 2023;Yong et al., 2021). Henri's line is a quick fit test that shows a good linear correlation with experimental points when matched to a statistical law on a Cartesian coordinate graph (Assani, 1999; Kasongo-Numbi, 2008; Mbo, 2011; Phogat et al., 2016).

2.2.1.3 Guimbel's Distribution

E.-J. Gumbel, a prominent mathematician, put forward a hypothesis stating that the double exponential law, or Gumbel's distribution, represents the ultimate form of the distribution of the maximum value of a sample of n values (Nadarajah, 2006; Cooray, 2010; Sevil et al., 2022; Fotse et al., 2024). Since the maximum annual value of a variable is the maximum of 365 daily values, this distribution can be used to describe the series of annual maximum values (Assani, 1999; Kasuwa, 2012). The distribution of extreme values in any distribution converges to the law of generalized extremes (GEV) (Berman, 1964; Vivekanandan., 2013; Facchinetti and Osmetti, 2013; Marra and Papalexiou, 2022).

The probability of not exceeding, F (X), of this distribution law is calculated by the following mathematical expression:

$$\mathrm{F(x)} = \exp[-(1 - \mathrm{c}\,\tfrac{\mathrm{x_i - a}}{\mathrm{b}})^{\frac{1}{\mathrm{c}}}] \tag{1}$$

Where, a is the position parameter, b the scale parameter, c the shape parameter and x_i is the variable, here the rainfall amounts and the temperatures. As the table 1 shows, Three laws can be distinguished based on the value of shape parameter c (Papalexiou and Koutsoyiannis, 2012).

Table 1: law's distribution

C	type	name	Lower bound	Upper bound
C > 0	**III**	$-X \approx$ **Weibull**	$-\infty$	$a+\frac{b}{c}$
C= 0	**I**	**Gumbel**	$-\infty$	$+\infty$
C < 0	**II**	**Fréchet**	$a+\frac{b}{c}$	$+\infty$

Then, the distribution function of Gumbel's law is expressed as follows:

$$F(X) = e^{-e^{-\frac{x_i - a}{b}}} \tag{2}$$

with the reduced variable of Gumbel, u, following: $u = \frac{x_i - a}{b}$ (3)

The distribution is then written as follows:

$$F(X) = e^{-e^{-u}} \tag{4}$$

and $u = -\ln\left[-\ln\left(F(X)\right)\right]$ (5)

The advantage of using the reduced variable is that the expression of a quantile is then linear. Indeed to find the value x_q of a quantile, corresponding to the distribution F $(x_q) = q$, as a function of the two parameters a and b, it suffices to use the following relation:

$$x_q = a + bu_q \tag{6}$$

It is possible to adjust a series of points by transferring them to a system of axes x - u. Once transferred, a straight line can be adjusted to pass through these points, allowing for the two parameters a and b of the law to be deduced. There are several methods for adjustment, including the graphic method (adjustment by eyes or using statistical regression), method of moments, etc (Reiss and Thomas, 2007; Mohamedmeki, 2020).

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Searching for signs of climate change

The climate is heavily influenced by precipitation, making it the primary factor that affects climate variations at all time scales. In this study, it will be a question of determining the number of days without rain, the number of successive days without rain as well as the length of the rainy season considering the hydrological years going from the month of October to the month of May.In order to detect signs of climate change, our approach involves monitoring the occurrence of short periods without rain lasting two to ten days, as well as noting the dates of the first and last rainfall. We can find out if the rainy season is experiencing an expansionary or contractive tendency by observing this information over time. As a result, we observed a shortening of the rainy season which is clearly visible with the help of the graphs presented in our work.

3.1.2 Gumbel analysis

The Henri test was employed to ascertain whether the temperatures and the maximum annual daily rains studied were in conformity with Gumbel's law. The outcome of this analysis enabled us to determine the probability of not surpassing and the recurrence interval of these diverse rains to forestall extreme and disastrous conditions.

Through the graphical adjustment method, we discovered that the annual maximum daily rains during our study period align with Gumbel's law, with a coefficient of determination of 0.9192 between the maximum annual daily rainfall studied and Gumbel's reduced experimental variables.

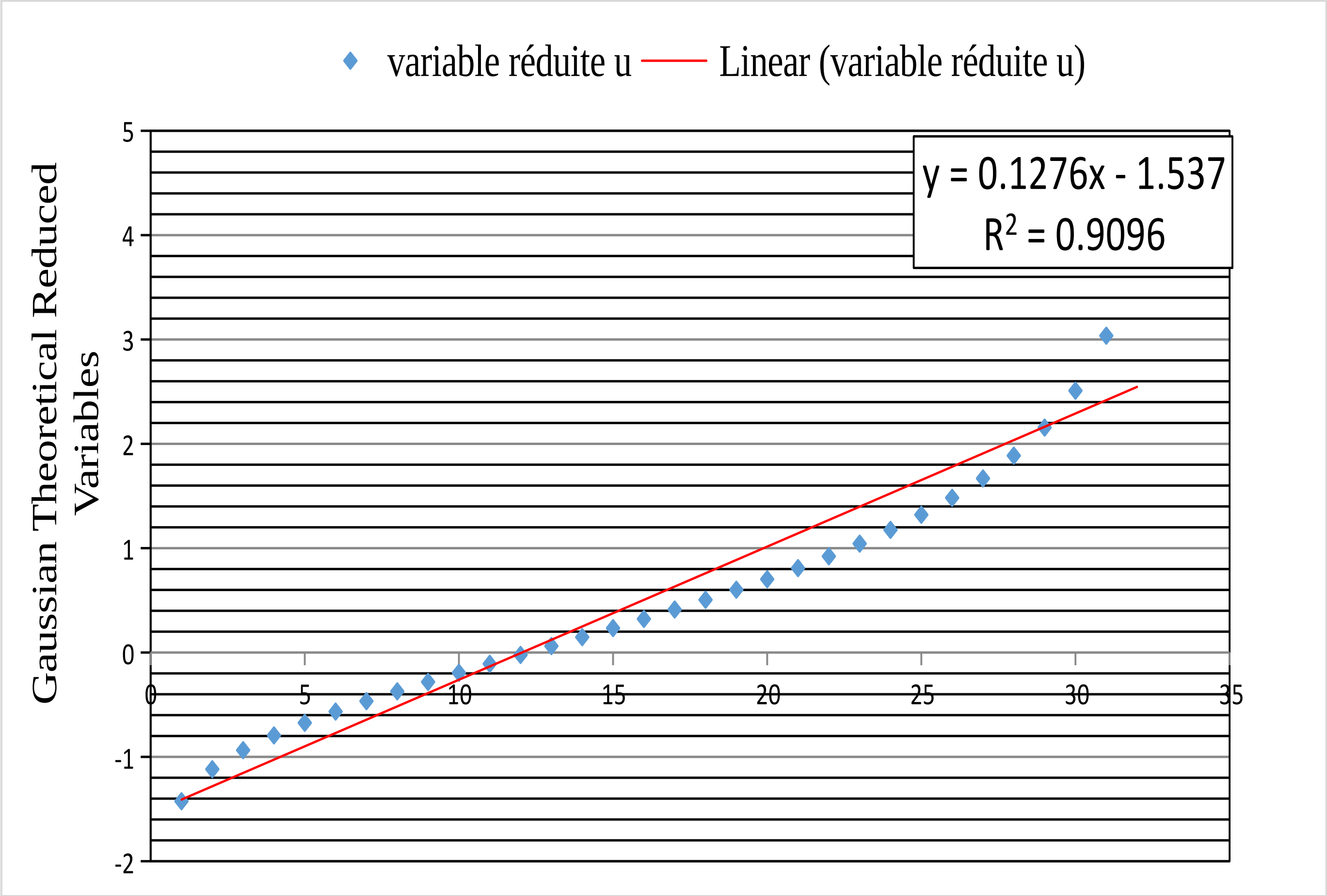

Figure 2: Henri's line for the fit test

3.1.3 Chronological analysis

We investigated variations in Kinshasa's rainy season rainfall totals as well as the frequency of rainy days in our research. Figure 4 depicts the rainfall's historical evolution, whereas Figure 3 illustrates the number of rainy days' chronological evolution. Through data analysis, we discovered that Kinshasa's rainy season has seen less rainy days overall over time, as seen by figure 5's smoothing line. However, figure 6's smoothing line clearly illustrates a rise in the amount of rain throughout the same period.

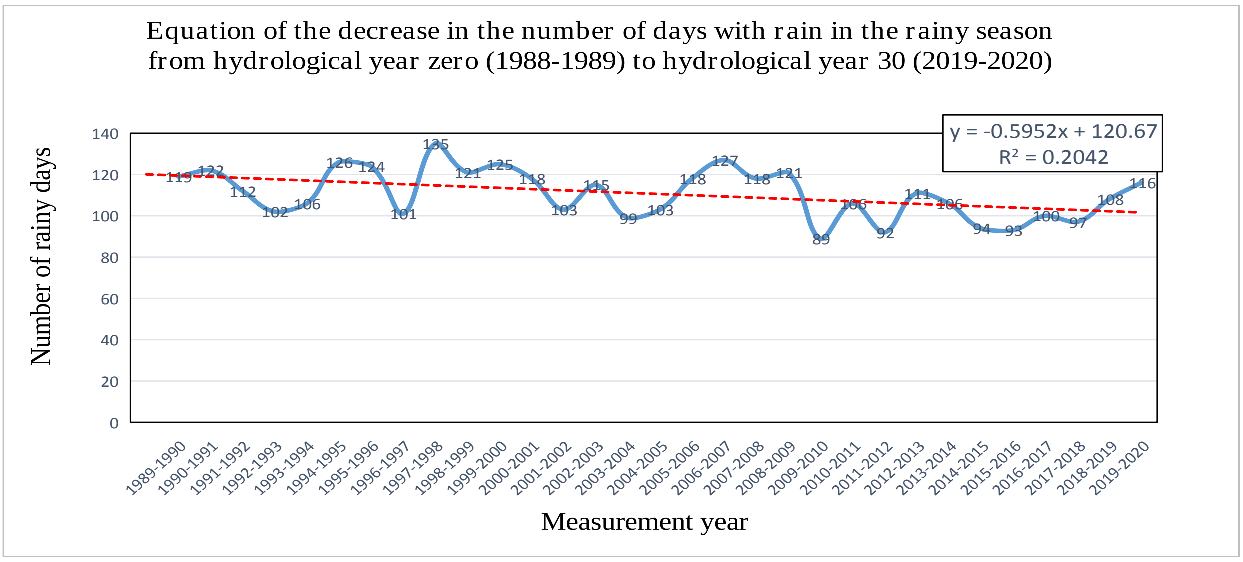

Figure 3: Chronological evolution of rainy days in Kinshasa from the hydrological year 1988-1989 to the hydrological year 2019-2020.

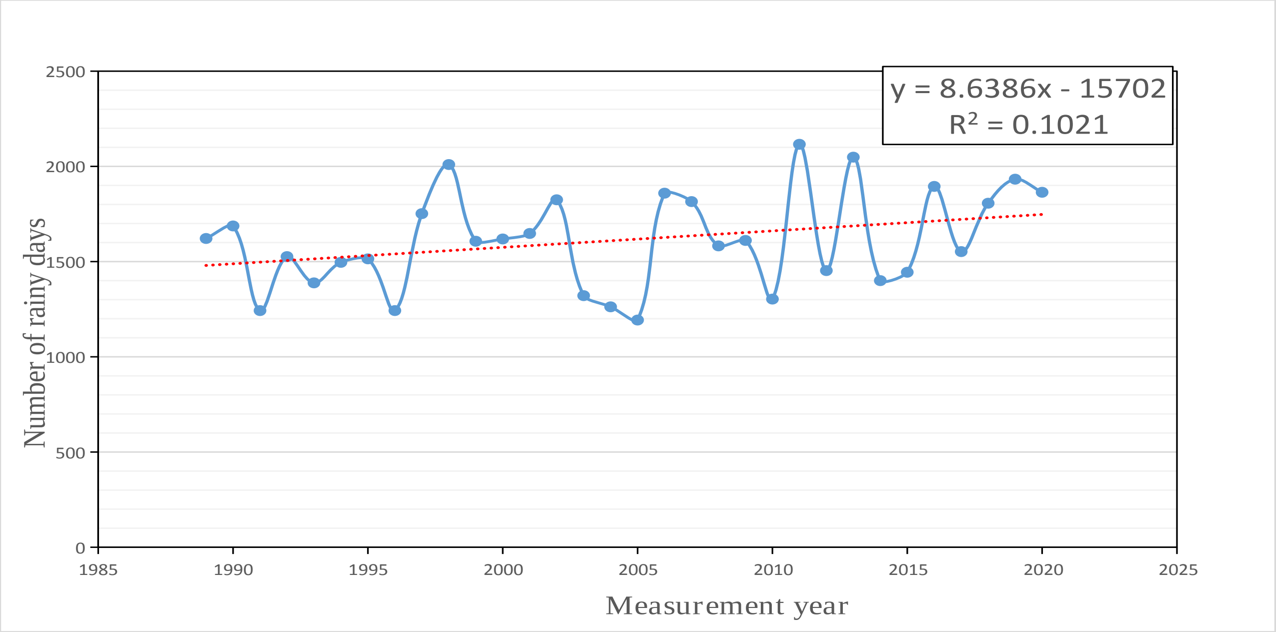

Figure 4: Chronological evolution of rainfall in Kinshasa from the hydrological year 1988-1989 to the hydrological year 2019-2020.

Figure 5 illustrates the graph of evolution of the number of episodes of two successive days without rain. According to the automatically generated smoothing line in Excel, there has been a decline in the frequency of these dry spells. The equation for this decrease is:

$$N_{E2JSP} = -0{,}0839t + 14{,}385 \tag{7}$$

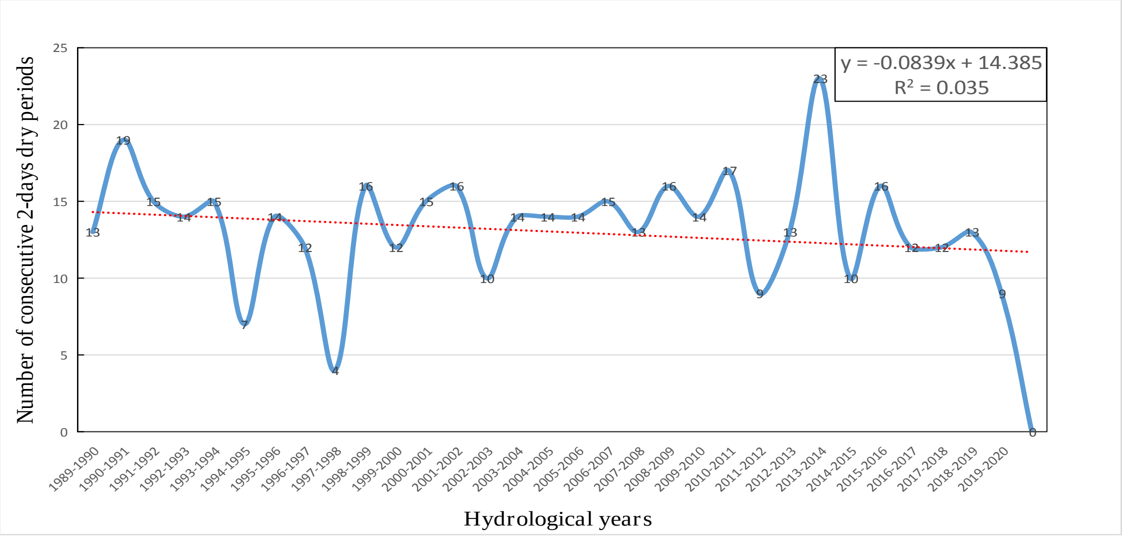

Figure 5: Number of episodes of two consecutive days without rain in Kinshasa during the period studied

The evolution of the number of episodes of three consecutive days without rain is shown in Figure 6, below. The automatic smoothing line generated by Excel shows that the number of these episodes is decreasing. The equation for this decrease is:

$$N_{E3JSP} = -0{,}0169t + 7{,}4968 \tag{8}$$

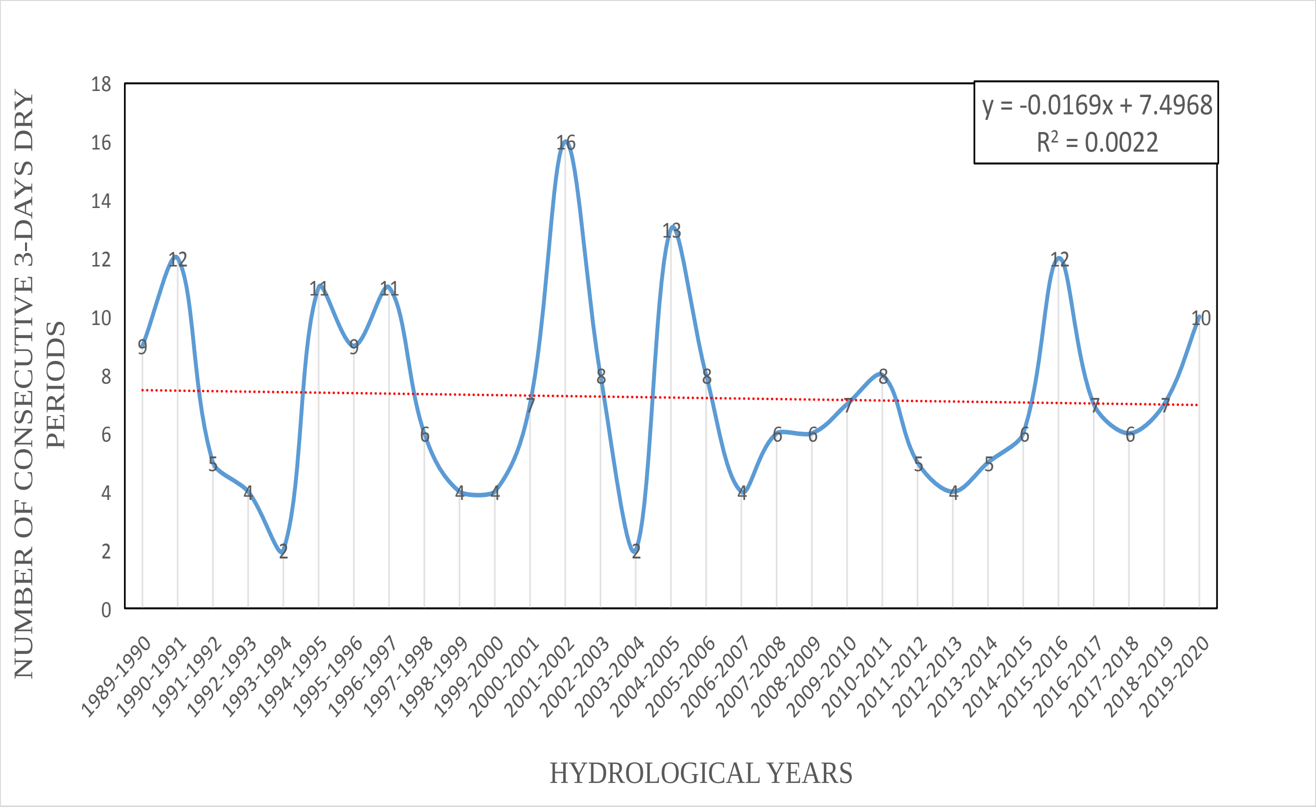

Figure 6 : Number of episodes of three consecutive days without rain in Kinshasa during the period studied

The evolution of the number of episodes of four successive days without rain is shown in Figure 7, below. The automatic smoothing line generated by Excel shows that the number of these episodes is increasing. The equation for this increase is:

$$N_{E4JSP} = 0{,}0085t + 5{,}3161 \tag{9}$$

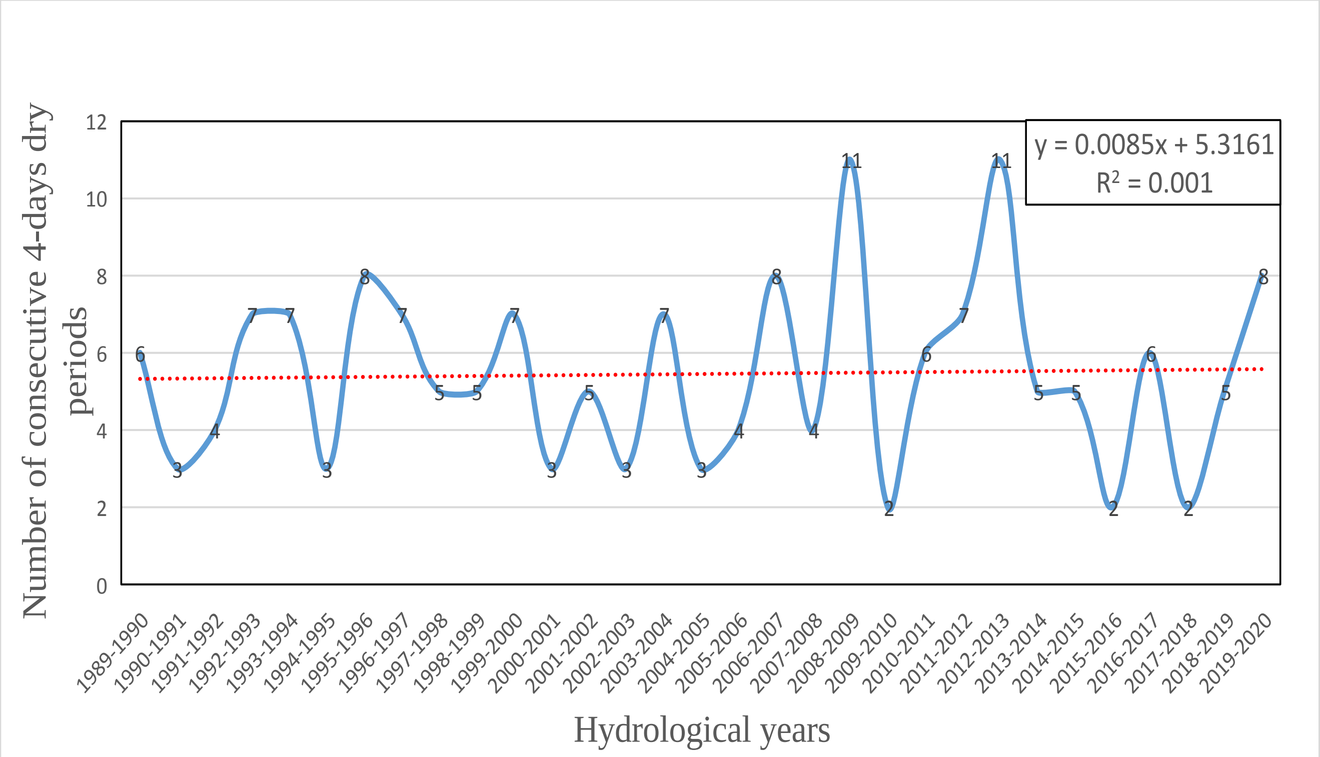

Figure 7 : Number of episodes of four consecutive days without rain in Kinshasa during the period studied

The evolution of the number of episodes of five consecutive days without rain is shown in figure (8.), below. The automatic smoothing line generated by Excel shows that the number of these episodes is increasing. The equation for this increase is:

$$N_{E5JSP} = 0{,}0278t + 1{,}6839 \tag{10}$$

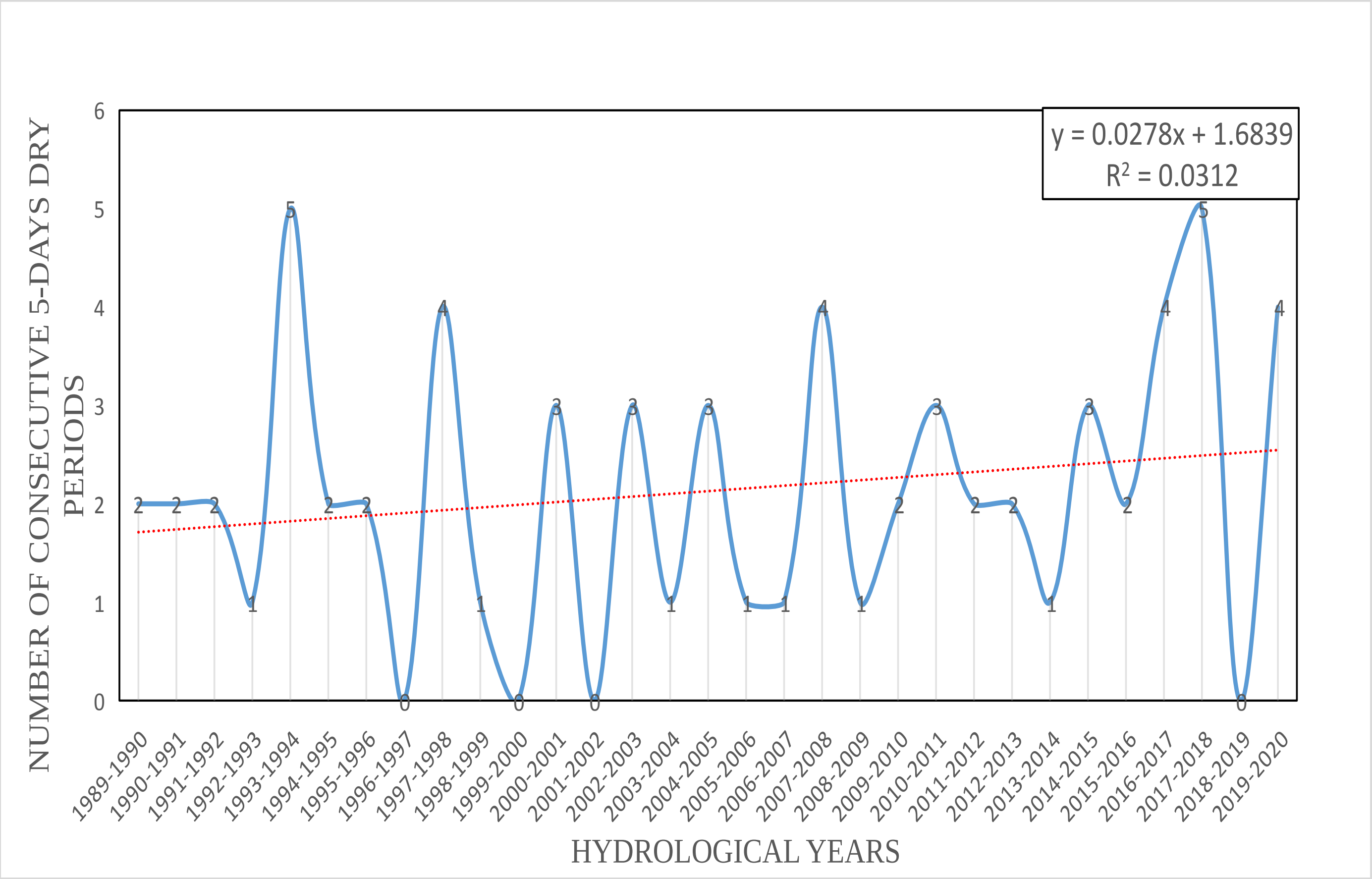

Figure 8 : Number of episodes of five consecutive days without rain in Kinshasa during the period studied

The evolution of the number of episodes of six consecutive days without rain is shown in Figure 9, below. The automatic smoothing line generated by Excel shows that the number of these episodes is increasing. The equation for this increase is:

$$N_{E6JSP} = 0{,}0355t + 0{,}8516 \quad (11)$$

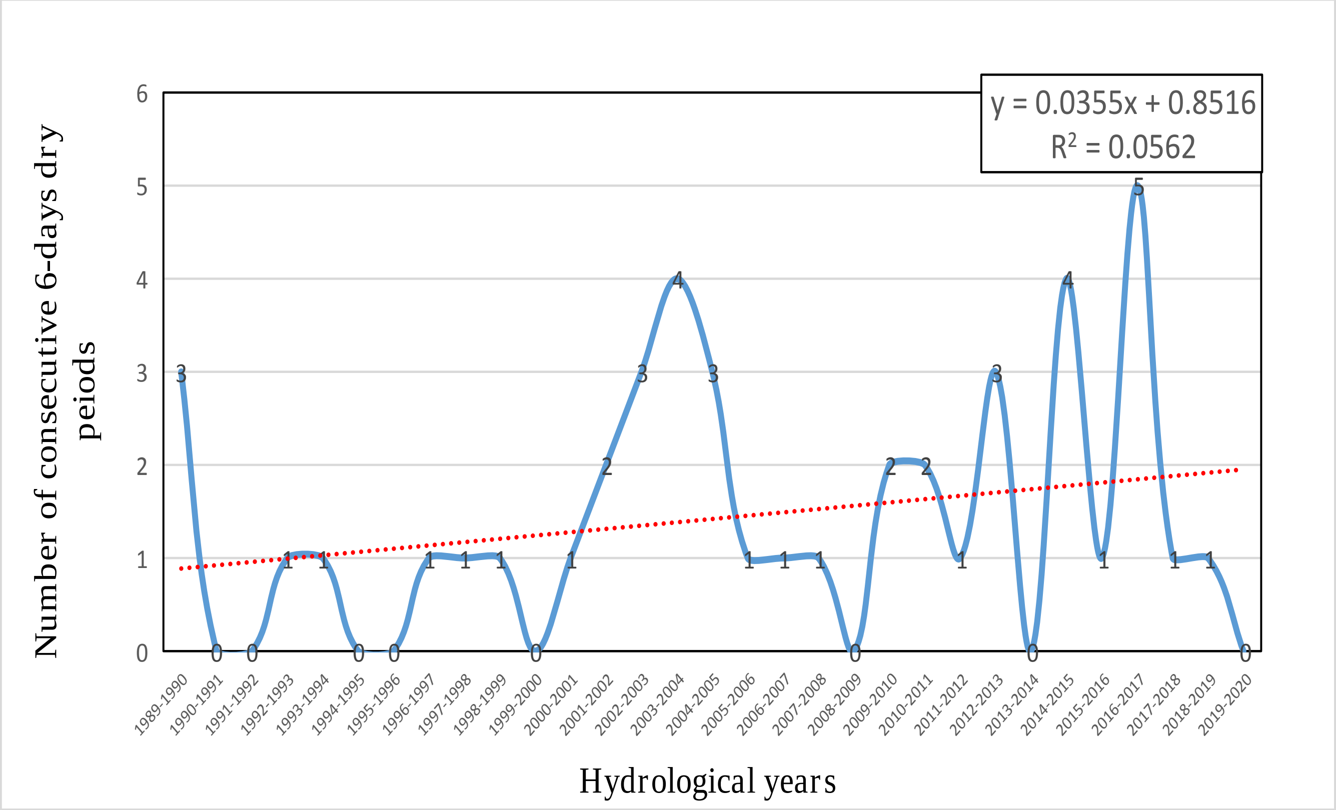

Figure 9 *:* Number of episodes of six consecutive days rain-free in Kinshasa during the period study

The evolution of the number of episodes of seven successive days rain-free is shown in Figure 11, below. The automatic smoothing line generated by Excel shows that the number of these episodes is increasing. The equation for this increase is:

$$N_{E7JSP} = 0{,}0552t + 0{,}1484 \quad (12)$$

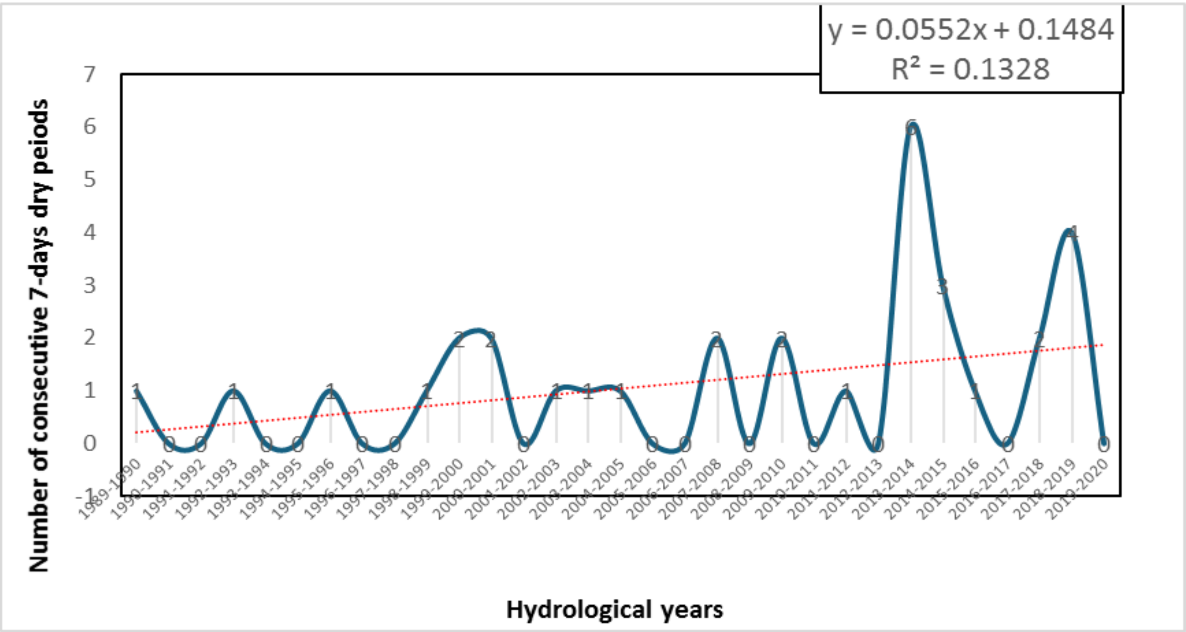

Figure 10 : Number of episodes of seven consecutive days rain-free in Kinshasa during the period study

3.2 Discussion

3.2.1 Decrease in rain-free days during the rainy season

Less rain during the rainy season is considered in this type of analysis as an indicator of the tendency toward drought in the region. If precipitation increases while the number of rainy days decreases, it falls in large quantities over a few days, increasing its intensity. Heavy rainfall can have negative impacts on groundwater replenishment in two ways.

First, when the intensity exceeds the rainfall infiltration rate into the soil, runoff increases, and less water infiltrates deeply into the ground to replenish the aquifer. Secondly, there may be a decrease in the number of rainy days during the rainy season, which leads to spaced-out rainfall events. The rainless period that occurs after heavy rains can lead to excessive drying of the soil. This drought can result in the absorption of most of the rainwater by the dry soil particles until the soil is completely saturated. Consequently, the replenishment of groundwater reserves may be constrained under such circumstances.

3.2.2 Effects of successive days without rain

According to our study, the number of rain-free periods lasting two or three days is decreasing, while the occurrence of consecutive periods without rain lasting four, five, six, or seven days is increasing. Data about rainless periods exceeding seven days suggests a stochastic pattern due to their infrequency. This reduction in rain-free days during the rainy season contributes to inadequate aquifer replenishment in Kinshasa, indicating a shift towards a drier climate regime for the capital and the rest of the country.

3.2.3 Frequency analysis

Over 32 years, we observed that the annual rainfall during the hydrological years follows the Place-Gauss law, also known as the normal distribution. The correlation between the experimental data points and the linear smoothing line is 0.9801, indicating a strong alignment. This conformity to the normal distribution law has allowed us to calculate the wet decade module and the dry decade module of our sample, which are respectively 1939.5 mm and 1288.5 mm. When the wet decade modulus, instead of recurring approximately every ten years, begins to manifest with increasing intervals longer than ten years and the dry modulus starts recurring more frequently than every ten years, it signifies a transition from humidity to aridity (Kasongo-Numbi, 2008). Even though our sample is short, 32 years, we can observe that a dry decadal modulus of 1288.5 with a confidence interval margin appears for the first time in the hydrological year 1990-1991 (1242.7 mm). Remarkably, it recurred 5 years later in 1995–1996 (1242.8 mm) then reappeared after only 8 years in 2003–2004 (1262.5 mm). Notably, both recurrence intervals of 5 years and 8 years fall below the anticipated theoretical recurrence of 10 years. Based on the limited dataset available, it has been observed that the wet decade modulus of 1939.5 mm occurred twice in the past: first in the hydrological year 1997-1998 (2008.7 mm) and then 20 years later, in 2018-2019 (1932.8 m). The fact that the sole recurrence period has already surpassed double its theoretical return period of 10 years suggests that this is an infrequent occurrence. Furthermore, the frequency of dry modules in the region surrounding the city of Kinshasa has increased, which indicates a potential threat of drought in the area.

4. CONCLUSION AND SUGGESTIONS

4.1 Conclusion

The sample size of 32 years, although small, generally accepted by hydrologists as the minimum size for reliable hydrological studies, revealed that Kinshasa city is susceptible to the effects of climate change that is affecting the world. Notably, the city faces not only the looming threat of drought, but also the increasing frequency of disasters such as floods and erosion.

The two harmful phenomena of aquifers are responsible for the drying up of rivers and springs during the dry season, which can result in flash floods, soil erosion, and lower water availability. Therefore, it is crucial to closely monitor rainfall and rainy days to understand their impact on ecosystems and humans.

4.2 Suggestions

The need of the hour is for climate change researchers to conduct more in-depth studies in order to refine our conclusions and gain a better understanding of the phenomenon. As concerned citizens, we are urging the authorities of Democratic Republic of Congo (DRC) and specifically Kinshasa to take proactive measures to address this urgent issue. This includes implementing preventive measures such as halting deforestation, planting trees, and creating areas of forced infiltration to minimize the loss of groundwater in runoff. Additionally, such measures will help combat the devastating impact of erosion and flooding caused by climate change.

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AUTHORS' CONTRIBUTIONS

Rais Seki Lenzo: Conceptualization, Software, Data Curation, Methodology, Formal analysis, Investigation, Writing - Original Draft Preparation, Writing - Review & Editing, Supervision. Jean-Pierre Kalay Kut: Software, Validation, Investigation, Writing - Review & Editing. Kasongo Numbi Kashemukunda: Project Administration, Funding Acquisition, Supervision, Validation, Writing - Review & Editing. Kaloucha Kanga Nsiama: Investigation, Validation, Writing - Review & Editing, Visualization. Gradi Kalonji Lelo: Writing - Review & Editing, Visualization, Ange Kra: Writing - Review & Editing, Visualization. Aurelie NKAYULU WA LUVUVAMU: Writing - Review & Editing, Visualization. Kevin LUMPUNGU LUTUMBA: Writing - Review & Editing, Visualization.

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