Atmospheric and Climate Sciences, 2025, 15(2), 462-475
https://www.scirp.org/journal/acs
ISSN Online: 2160-0422
ISSN Print: 2160-0414

Indicators of Spatio-Temporal Changes in Rainfall in Forest Guinea

Piou Dobo Guilavogui[1*], Ibrahima Kalil Kante[1], Magbini Tokpa Mamy[2]

[1]Laboratoire d'Enseignement et Recherche en Energétique Appliquée (LEREA), Département de Physique, Faculté des Sciences, Université Gamal Abdel Nasser de Conakry, Conakry, République de Guinée
[2]Département de Météorologie, Faculté de Science de l'Environnement, Université de N'Zérékoré, Nzérékoré, République de Guinée
Email: *guilaopiou0@gmail.com

How to cite this paper: Guilavogui, P.D., Kante, I.K. and Mamy, M.T. (2025) Indicators of Spatio-Temporal Changes in Rainfall in Forest Guinea. *Atmospheric and Climate Sciences*, **15**, 462-475.
https://doi.org/10.4236/acs.2025.152024

Received: February 19, 2025
Accepted: April 21, 2025
Published: April 24, 2025

Abstract

The Republic of Guinea has a humid tropical climate, characterized by a dry season influenced by the harmattan and a rainy season influenced by the West African monsoon, with an average annual rainfall of 1835 mm. In its southern part, rainfall events are intense due to the early arrival and late retreat of the Inter-Tropical Convergence Zone (ITCZ). This study examines statistical indicators of the spatio-temporal variability of rainfall in the forest region (south) of the Republic of Guinea. The methodological approach adopted revolves around the collection and processing of data and the analysis of results. The data used are provided by the Agency National of Meteorology (ANM), covering a period from 1994 to 2023, and come from four (4) synoptic meteorological stations in Guinea Forester. Our results show that, since 1994, Forester Guinea has experienced rainfall variability marked by alternating rainfall heights with variations linked to altitude. We found that average monthly rainfall varies from station to station: 151.6 mm and 165.1 mm for Beyla and N'Zérékoré stations, 182.7 mm and 188.8 mm for Macenta and Yomou stations. Annual rainfall averages between 1800 and 2300 mm, depending on the location.

Keywords

Indicators, Events, Rainfall, Guinea-Forester

1. Introduction

In recent years, West Africa has experienced a marked increase in extreme hydro-climatic events, such as devastating floods and severe droughts [1]. These extreme phenomena are due respectively to the intensification of exceptional rainfall episodes and persistent precipitation deficits [2]. Such events have a severe impact on society, the economy and the ecosystem [3]. Examples include the devastating floods of 2009 in Ouagadougou, Burkina Faso, following nearly 300 mm of rain in ten hours [4], and the droughts of the 1970s and 1980s in the Sahel [5].

Today, several studies have focused on analyzing the evolution of extreme precipitation in Africa, precisely north of the Equator [6]-[10]. These studies provide essential insights into climate trends and the potential impacts of climate change in this region. Other researchers have analyzed daily data from six weather stations in West Africa (two in Gambia and four in Nigeria) over the period 1961-2000. They observed significant upward trends in annual maximum daily rainfall at one of these stations [11].

In Africa, frequent flooding and water-borne and vector-borne diseases exacerbate health crises. Although the continent contributes the least to global warming, it suffers all its consequences. Extreme events such as floods and droughts are occurring more frequently and with increasing severity. Some regions of Africa are more exposed to these phenomena than others. It is likely that the increased frequency of recorded disasters is the result of a combination of climate alteration and socio-economic and demographic changes [12].

In other countries, such as Senegal, the Republic of Guinea and Guinea-Bissau, water management remains a major problem. Demand for water continues to grow, while the effects of climate change tend to limit its availability [13]. Some authors have investigated the evolution of extreme precipitation in Guinea Conakry and have noted a decrease over the period 1955-2006 [14].

1.1. Context and Issues

In the forest region, the household economy is essentially based on the exploitation of local natural resources, which are dependent on rainfall. The distribution and quantity of rainfall, its start and end dates, and the frequency of dry and wet episodes occurring during the season, due to their variability and unfavorable configuration, have a particularly significant impact on agropastoral production and on the level of disaster risk [15]. In addition, abundant rainfall in record time leads to pluvial flooding. In addition to these factors, high temperatures, heat waves and pockets of drought mean that Guinea-Forester is vulnerable to climate change. Very few studies have been carried out on this vulnerability, hence the need for a study on indicators of spatio-temporal changes in rainfall in this forest region.

1.2. Presentation of the Study Area

The forest region corresponds to the southern part of Guinea, covering 20% of the country's total surface area. Its relief features two mountains: Mount Simandou and Mount Nimba, the latter being the highest in the country at 1752 m altitude. The region's climate is characterized by an exceptionally long rainy season (between seven and nine months). It has an average rainfall of around 2500 mm/year and is the area with the highest biomass coverage in the country [16] [17]. This region lies between 8˚39'36'' north, 8˚57'00'' west, and shares international borders with Côte d'Ivoire to the East, Liberia to the South and Sierra Leone to the West (**Figure 1**).

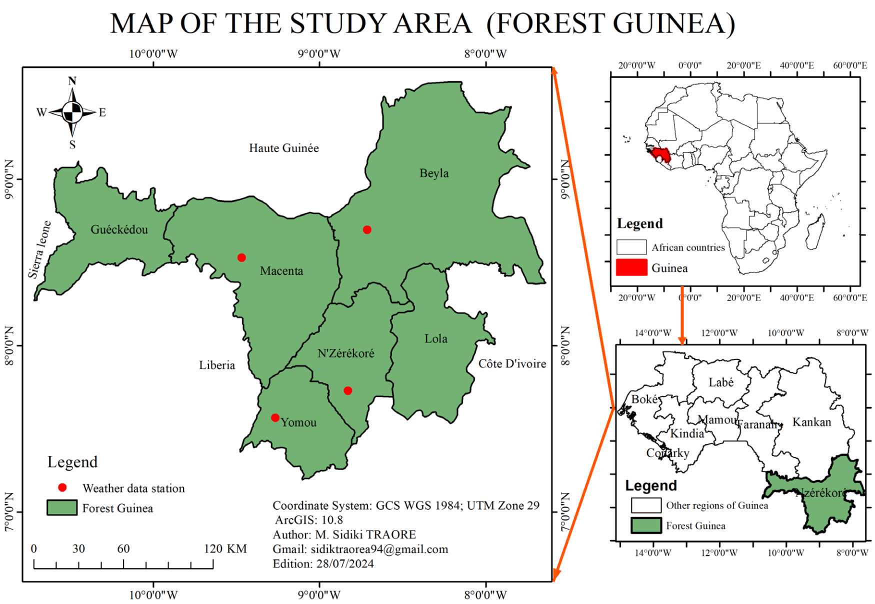

Figure 1. Geographical location of Forest Guinea. (Source: M. Sidiki Traore)

2. Data and Methods

2.1. Data Used

For this work, the data used are provided by the Agency National Meteorology (ANM) and include climatological series related to daily, monthly and annual precipitation from 1994 to 2023. The choice of this period is justified by the need to consider a maximum number of precipitations in the observation networks and to have a long series to better analyze precipitation variability in the study area.

2.2. Methodology Adopted

The methodological approach begins with a search for general and specific scientific papers and other documents that have helped to better define the aspects of the subject. An analysis of the literature reviewed enabled us to identify the methods best suited to the study. Software and formulas were used to produce average seasonal rainfall cycles and maps, and to calculate certain values and statistical tests.

- ***Coefficient of variation***

This is the ratio between the standard deviation and the mean. It shows whether or not there is a high degree of variation in the data. When it is less than 100, it indicates a low level of data dispersion. On the other hand, a C_v value > 100 means that there is a high degree of variation in the data. In this case, we can assume the presence of heterogeneity. Its mathematical expression is given by the equation:

$$C_v = \frac{\sigma}{X} \times 100 \tag{1}$$

- ***Nicholson rainfall index***

This is an index that measures the deviation from an average established over a long period based on station data. The annual rainfall index is defined as a reduced-centered variable [18] [19]. It is obtained by the equation:

$$Ip = \frac{X_i - X_m}{\sigma} \tag{2}$$

where X_i: rainfall in year i; X_m: mean interannual rainfall; σ: standard deviation of interannual rainfall; Ip: rainfall index. The rainfall index determines the number of surplus or deficit years and the corresponding significance in terms of the magnitude of the climatic phenomenon (**Table 1**).

Table 1. Classification of rainfall index interpretation grids.

Precipitation Index Class	Interpretation Grids
$Ip > 2$	Extreme humidity
$1 < Ip < 2$	High humidity
$0 < Ip < 1$	Moderate humidity
$-1 < Ip < 0$	Moderate drought
$-2 < Ip < -1$	Severe drought
$Ip < -2$	Extreme drought

Source: [18] [19].

- ***Precipitation trends***

Trends in maximum and minimum rainfall have been highlighted by a regression line of the type given by the equation:

$$y = ax + b \tag{3}$$

where y is the value of the variable whose trend is being investigated; a is obtained by calculating the slope, the directing coefficient of the regression whose positive (+) or negative (−) signs express respectively the increasing and decreasing trend over time x and b, a constant such that:

$$a = \frac{\left(\sum y\right)\left(\sum x^2\right) - \left(\sum x\right)\left(\sum xy\right)}{N\sum x^2 - \left(\sum x\right)^2};\quad b = \frac{N\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{N\sum x^2 - \left(\sum x^2\right)}$$

where the coefficients a and b are respectively the y-intercept and the slope of the line

- ***Methods for detecting breaks in rainfall series***

There are several methods for detecting stationary breaks in rainfall series. In this study, the Pettitt test was used to detect stationary breaks in rainfall data. The series studied is divided into two samples of size m and n respectively. The values of the two samples are grouped together and ranked in ascending order. The sum of the ranks of the elements of each sub-sample in the total sample is then calculated. A statistical study is defined on the basis of the two sums, which is thus determined and tested under the null hypothesis that both sub-samples belong to the same population. This test is based on the calculation of the variable $U(t,N)$ defined by equation [20]

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=t+1}^{N} D_{ij} \tag{4}$$

with

$D_{ij} = \operatorname{sign}(x_i - x_j)$ hence, so, in which $\operatorname{sign}(x) = 1$ if $x > 0$ and -1 if $x < 0$

- ***Calculating average variations in rainfall data***

For rainfall variables with a break in the time series, it is interesting to calculate the mean variations on either side of the break by applying the equation [21]:

$$D = \frac{X_j}{X_i} - 1 \tag{5}$$

where X_j represents the average over the period after the break and X_i the average over the period before the break.

3. Results and Discussion

3.1. Results

3.1.1. Spatial Distribution of Rainfall in Forest Guinea

Analysis of mean annual rainfall in the forest region over recent years (1994-2023) shows a heterogeneous distribution of rainfall across the region, with a gradual increase in rainfall levels from northwest to southeast. Areas of high rainfall are mainly located in the Guéckédou and Macenta zones, where values reach 2357.7 mm and 2267.1 mm respectively. Medium rainfall areas, with levels between 1904.7 mm and 1995.3 mm, are found in Yomou and N'Zérékoré, while low rainfall areas with intervals between 1632.9 mm and 1723.5 mm are found in Lola and Beyla (**Figure 2**).

3.1.2. Statistical Analysis of Rainfall

In this study, the average annual rainfall in N'Zérékoré was 1981.5 mm, 2265.5 mm in Yomou, 2192.2 mm in Macenta and 2126 mm in Beyla. Maximum annual rainfall averaged 3063 mm in N'Zérékoré, 3369 mm in Yomou, 3474 mm in Macenta and 3229 mm in Beyla. **Table 2** gives details of the statistical coefficients of rainfall at these stations. We note that the coefficients of variation (C_v) range from 33.09% to 42.19% and are less than 100, which means that rainfall in our study area shows little variability.

3.1.3. Interannual Variability of Rainfall Indices in Forest Guinea

Analysis of rainfall indices (*Ip*) in **Figure 3** shows that positive (surplus) rainfall anomalies vary from 0 to 2, characterizing rainy periods, marked by indicators of extreme rainfall events. Those below 0, on the other hand, are negative (deficit) anomalies and indicators of rainfall regression. Looking at **Figure 3(a)**, the

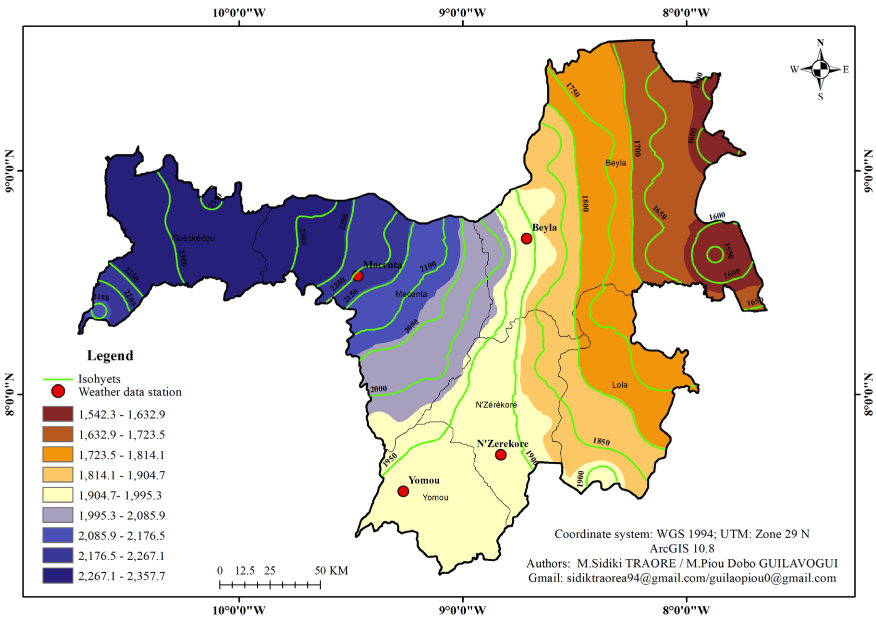

Figure 2. Carte de distribution des précipitations annuelles de la Guinée Forestiere. (Source: M. Sidiki Traoré and Đ. Piou Dobo Guilavogui)

Table 2. Statistical parameters of annual precipitation.

Statistical parameters	Pmax (mm)	Pmoy (mm)	Pmin (mm)	Standard deviation	C_v
N'Zérékoré	3063	1981.5	900	696.8	35.16%
Yomou	3369	2265.5	986	810.2	35.76%
Macenta	3474	2192.2	646	924.9	42.19%
Beyla	3229	2126.0	986	703.6	33.09%

N'Zérékoré synoptic station shows that the years with the most deficit are 1996 and 2000 to 2007. This deficit is marked by a long period of persistent drought at this synoptic station. The most surplus years are 1998, 2014 and 2018 to 2023. The other synoptic stations (**Figures 3(b)-(d)**), Yomou, Macenta and Beyla respectively, have the same rainfall characteristics as the N'Zérékoré station. In terms of positive and negative rainfall indices (*Ip*), the study area as a whole has experienced years of high humidity and years of strong drought sequences over recent decades.

Ip grids were used to characterize the level of rainfall deficits observed and to assess the extent of drought sequences or humidity (**Table 3**). Analysis of this table shows that the study area recorded an average of 00% years with extreme humidity, 17.5% years with high humidity, 40.84% years with moderate humidity, 15% years with moderate drought, 26.67% years with high drought and 00% years with extreme drought. The types of rainy years recorded are heterogeneous from one synoptic station to another. It is worth noting that for the entire 1994-2023 series, there were eight years (1996, 2001, 2002, 2003, 2004, 2005, 2006 and 2007) of severe drought at all stations, indicating the existence of hydroclimatic hazards in Guinea-Forester.

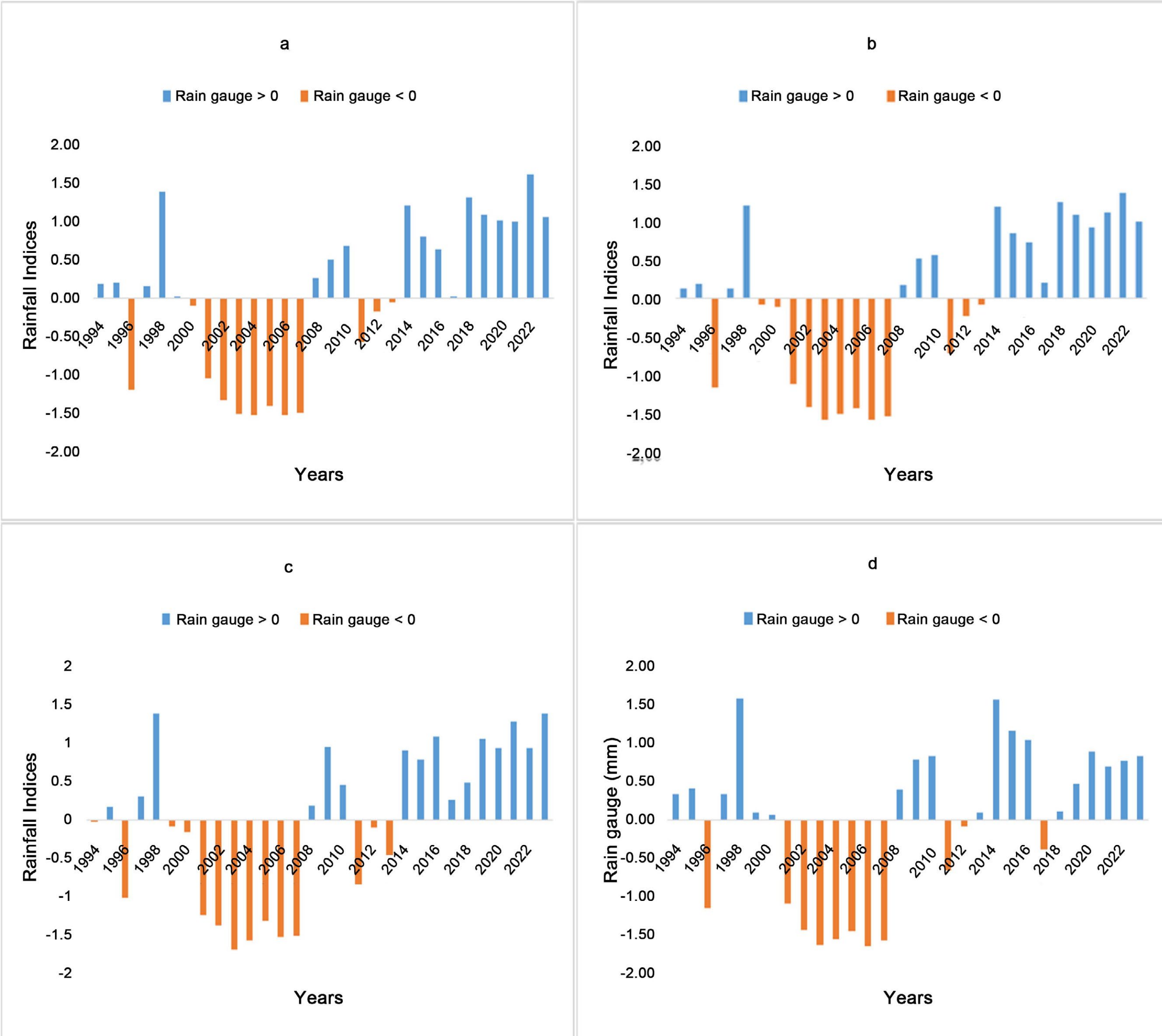

Figure 3. Interannual change in precipitation indices: a) N'Zérékoré station, b) Yomou station, c) Macenta station, d) Beyla station.

Table 3. Classification of years according to rainfall index grids in the study area.

Synoptic stations	Rainfall events					
	Extreme humidity	High humidity	Moderate humidity	Moderate drought	Severe drought	Extreme drought
N'Zérékoré	None	1998, 2014 2018, 2019 2022, 2023	1994, 1995 1997, 1999 2008, 2009 2010, 2015 2016, 2017 2020, 2021	2000, 2011 2012, 2013	1996, 2001 2002, 2003 2004, 2005 2006, 2007	None
Number	**00**	**06**	**12**	**04**	**08**	**00**
Percentage	**00%**	**20%**	**40%**	**13.33%**	**26.67%**	**00%**

Continued

Macenta	None	1998, 2016 2019, 2021 2023	1995, 1997 2008, 2009 2010, 2014 2015, 2017 2018, 2020 2022	1994, 1999 2000, 2011 2012, 2013	1996, 2001 2002, 2003 2004, 2005 2006, 2007	None
Number	**00**	**05**	**11**	**06**	**08**	**00**
Percentage	**00%**	**16.67%**	**36.67%**	**20%**	**26.67%**	**00%**
Beyla	None	1998, 2014 2015, 2016	1994, 1995 1997, 1999 2000, 2008 2009, 2010 2013, 2018 2019, 2020 2021, 2022 2023	2011, 2012 2017	1996, 2001 2002, 2003 2004, 2005 2006, 2007	None
Number	**00**	**04**	**15**	**03**	**08**	**00**
Percentage	**00%**	**13.33%**	**50%**	**10%**	**26.67%**	**00%**
Yomou	None	1998, 2014 2018, 2019 2021, 2022	1994, 1995 1997, 2008 2009, 2010 2015, 2016 2017, 2020 2023	1999, 2000 2011, 2012 2013	1996, 2001 2002, 2003 2004, 2005 2006, 2007	None
Number	**00**	**06**	**11**	**05**	**08**	**00**
Percentage	**00%**	**20%**	**36.67%**	**16.67%**	**26.67%**	**00%**
Average	**00%**	**17.5%**	**40.84%**	**15%**	**26.67%**	**00%**

3.1.4. Interannual Rainfall Dynamics in Forest Guinea

For the four (4) stations, Figure 4 shows interannual rainfall variability in the forest region, with rainfall amounts varying between 600 mm and 1600 mm during the period 2000 to 2007. For all stations, rainfall increased slightly from 1994 to 2000. And fall from 2001 to 2007, with higher rainfall recorded from 2008 to 2023. The N'Zérékoré station (Figure 4(a)) shows that rainy years are numerous and varied, but 2008 and 2022 remain the wettest years, with rainfall totaling 3000 mm. We note that from 2007 to 2023, recorded rainfall is at its highest, varying between 1500 mm and 3000 mm, with peaks in 2010, 2013, 2019 and 2022. At the Yomou station (Figure 4(b)), we note that during our study period, rainfall peaks were identified in 1998 (3400 mm), 2009 (3000 mm), 2010 (3000 mm), 2014 to 2023, which constitute the wettest years. Figure 3(c) shows a very marked variability at the Macenta station, with low rainfall values recorded during the period from 2001 to 2007. Over our study period, the years 1998, 2009, 2014 to 2016 (3000 mm - 3010 mm) and 2018 to 2023 (2990 mm - 3000 mm) are identified as the wettest years. Considering the Beyla station (Figure 4(d)), we note a similar variability to that of Macenta during the period 2001 to 2007. At this station, 1998

(3300 mm) and 2014 (3350 mm) are the two (2) rainfall peaks of our study period. We have identified the following years 1998 (3300 mm), 2007 to 2010 (2700 mm to 2800 mm), 2014 to 2016 (3000 mm - 3010 mm) and 2018 to 2023 (2990 mm - 3000 mm) as being the most rainy years due to the quantities recorded.

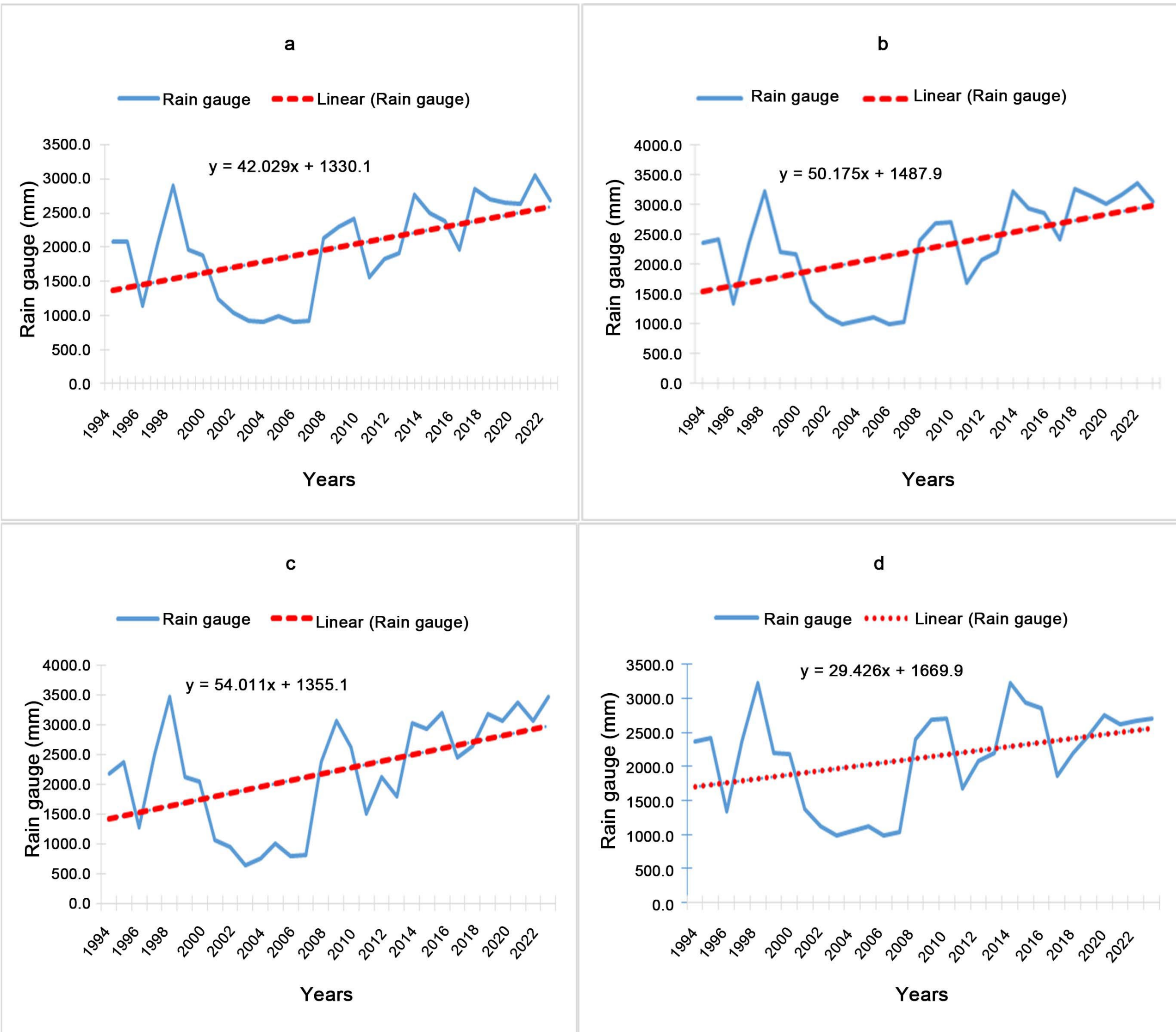

Figure 4. Interannual rainfall variability from 1994 to 2023: a) N'Zérékoré station, b) Yomou station, c) Macenta station, d) Beyla station.

3.1.5. Detection of Stationary Break in Rainfall Series

Application of the Pettitt test (**Figure 5**) to rainfall series from 1994 to 2023 in Guiana-Forester shows that there has been a break in stationary at all the stations studied. There was a break in the same year for **Figure 5(b)** and **Figure 5(c)** (2013) and a different date for **Figure 5(a)** and **Figure 5(d)** (2014 and 2007 respectively). Given that the calculated p values are below the alpha significance level equal to 0.05, we must reject the null hypothesis and retain the alternative hypothesis of a break in stationary in the rainfall series studied.

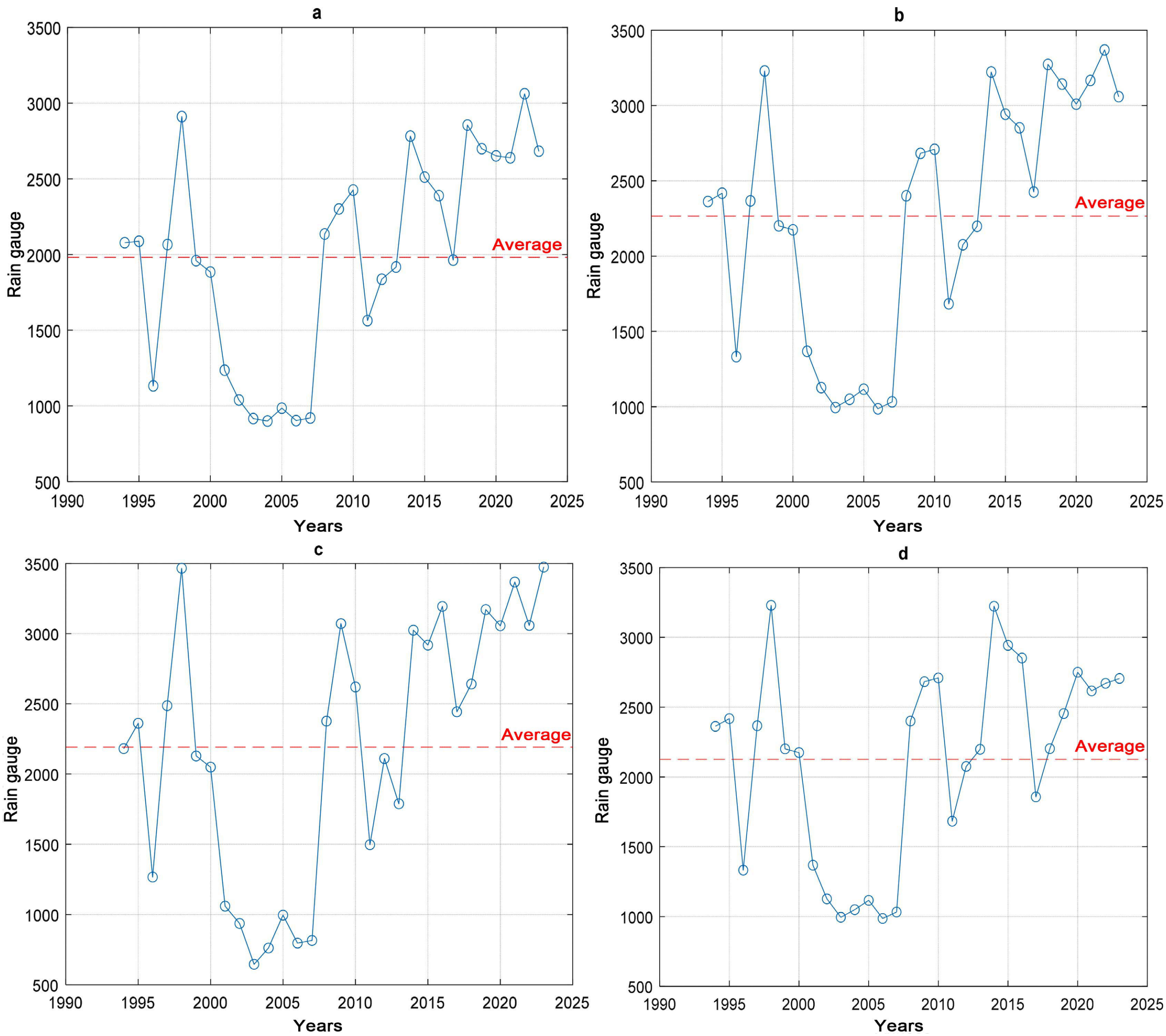

Figure 5. Break in stationarity in rainfall series by Pettitt test from 1994 to 2023: a) N'Zérékoré station, b) Yomou station, c) Macenta station, d) Beyla station.

In order to verify the breaking levels of these graphs, Pettitt's statistical test using Monte Carlo simulations with a 99% confidence interval presented the results below (**Table 4**). Analysis of this table reveals that the rainfall series as a whole are homogeneous and show break-up times.

Table 4. Results of Pettitt's statistical test.

Stations	Pettitt's test characteristics			
	K	Breaking time	p values	*α*
N'Zérékoré	168	2014	0.001	0.05
Yomou	180	2013	0.001	0.05
Macenta	166	2013	0.001	0.05
Beyla	146	2007	0.006	0.05

3.1.6. Impact of Lower or Higher Annual Rainfall

Table 5 shows the increase in mean rainfall heights at the various stations expressed by the increase in rainfall deficit. Analysis of the table reveals that the rainfall increase deficit is higher at the Macenta station than at the other three stations. However, for all four stations, the rainfall increase deficit recorded is around 0.04% for the stations (Yomou and N'Zérékoré) and 0.28% for Macenta and Beyla.

Table 5. Rainfall increase deficits recorded at various stations.

Stations	Date of break	Average before break	Average after break	Deficit (%)
N'Zérékoré	2014	1646.8	2623.9	**0.59**
Yomou	2013	1858.4	3046.1	**0.64**
Macenta	2013	1770	3035.1	**0.71**
Beyla	2007	1748.1	2501.4	**0.43**

3.2. Discussion

Climate change in the forest region is reflected in the increasing frequency of extreme climatic events. Indeed, rainfall indices **(**Figure 3) range from −1.5 to 1.6 for the N'Zérékoré synoptic station, −1.6 to 1.4 for the Yomou synoptic station, -1.7 to 1.4 for the Macenta synoptic station and −1.6 to 1.6 for the Beyla synoptic station over the study period (1994-2023). HE risks associated with extreme rainfall events are discussed, as there is little research in Guinea that systematically reports the losses and effects due to these events, yet their impacts on agricultural production, rural livelihoods and urban and economic sectors are obvious and considerable. Analysis of Figure 4 shows that average annual rainfall is unevenly distributed and varies across Forest Guinea. They range from 986 mm to 3229 mm for the Beyla and Yomou stations, 646 mm to 3474 mm (Macenta station) and 900 mm to 3063 mm for the N'Zérékoré station. For all stations, rainfall rose slightly from 1994 to 2000, then fell from 2001 to 2007, with higher levels recorded from 2008 to 2023. Similarly, Figure 5 shows that annual maximum precipitation experienced a very remarkable increase in rainfall height between 2014-2023 with trend and determination coefficients of 42.03 and 0.282; 50.18 and 0.297; 54.01 and 0.264 and 29.43 and 0.134 for Figures 4(a)-(d) respectively. The rainfall increase deficits observed show that the periods after the break were rainier than those before. In addition, the rupture periods cited in (Table 5) are not significant, but rather a spatio-temporal change in rainfall for the various localities in the study area. These changes in rainfall data show an increase in rainfall of 0.59% at the N'Zérékoré station, 0.64% at Yomou, 0.71% at Macenta and 0.43% at Beyla. These results show that the absence of a significant break does not guarantee the absence of a drop in rainfall. Indeed, the break levels defined do not take into account the abruptness with which the change occurs in the rainfall data. The classification of a break as significant or insignificant does not reflect the extent of the phenomenon, or at least does not allow us to judge the significance of the decrease or increase recorded within the precipitation series. This result is in line with those found by other African researchers [22]-[24].

4. Conclusion

The analysis of changes in rainfall series has highlighted a number of factors affecting rainfall in the study area. Indeed, the research noted that the climatology of Guinea Forester is the result of the dynamics of atmospheric pressure centers, including the Azores anticyclone in the northern hemisphere and, more specifically, the Saint Helena anticyclone in the southern equatorial Atlantic. The results showed that atmospheric conditions relating to pressure and humidity contribute to the surplus or lack of rainfall in the study area, according to the wet and dry periods identified in this research. As a result, these optimum atmospheric conditions (relative humidity) have contributed to the development of rainfall surpluses and deficits recorded over the last thirty years (1994-2023), marked by extreme events, followed by floods and flooding in the study area. Generally speaking, several factors interact, including atmospheric conditions, oceanic and continental surface conditions, wind speed and direction, and surface conditions in the rainfall process in West Africa.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Aguilar, E., Aziz Barry, A., Brunet, M., Ekang, L., Fernandes, A., Massoukina, M., *et al.* (2009) Changes in Temperature and Precipitation Extremes in Western Central Africa, Guinea Conakry, and Zimbabwe, 1955-2006. *Journal of Geophysical Research*: *Atmospheres*, **114**, D02115. https://doi.org/10.1029/2008jd011010

[2] Amraoui, L., Sarr, M.A. and Soto, D. (2011) Analyse rétrospective de l'évolution climatique récente en Afrique du Nord-Ouest. *Physio-Géo*, **5**, 125-142. https://doi.org/10.4000/physio-geo.1959

[3] Ardoin, B.S. (2004) Variabilite hydroclimatique et impacts sur les ressources en eau de grands bassins hydrographiques en zone soudano-sahelienne. Université de Montpellier II. https://www.documentation.ird.fr/hor/fdi:010036277

[4] Bambara, D., Thiombiano, A. and Hien, V. (2016) Changements climatiques en zones nord-soudanienne et sub-sahélienne du Burkina Faso: Comparaison entre savoirs paysans et connaissances scientifiques. *Revue d'Écologie* (*La Terre et La Vie*), **71**, 35-58. https://doi.org/10.3406/revec.2016.1864

[5] Béavogui, K., Badiane, D., Sall, S.M. and Diaby, I. (2011) Approche climatologique des phenomenes pluvio-orageux en guinee. *Journal des Sciences Pour l'Ingénieur*, **13**, 71-77. https://www.scirp.org/reference/referencespapers?referenceid=2628800

[6] Dacosta, H., Konaté, Y.K. and Malou, R. (2002) La variabilité spatio-temporelle des précipitations au Sénégal depuis un siècle. 2002 *FRIEND Conference*, Le Cap, 18-22 March 2002, 499-506.
https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDe-

tail&idt=14056028

[7] Dai, A., Lamb, P.J., Trenberth, K.E., Hulme, M., Jones, P.D. and Xie, P. (2004) The Recent Sahel Drought Is Real. *International Journal of Climatology*, **24**, 1323-1331. https://doi.org/10.1002/joc.1083

[8] Chamani, E., Rezaei, Z., Dastjerdi, K., Javanshir, S., Khorsandi, K. and Mohammadi, G.A. (2019) Evaluation of Some Genes and Proteins Involved in Apoptosis on Human Chronic Myeloid Leukemia Cells (K562 Cells) by *Datura innoxia* Leaves Aqueous Extract. *Journal of Biomolecular Structure and Dynamics*, **38**, 4838-4849. https://doi.org/10.1080/07391102.2019.1691661

[9] Fossou, R.M.N.G., Soro, E.G., Dosso, S. and Gone, L.D. (2020) Variabilité de la pluviométrie en afrique de l'ouest: Cas de la région du n'zi au centre-est de la côte d'ivoire. *Revue Ivoirienne des Sciences et Technologie*, **36**, 171-192. https://revist.net/REVIST_36/11-ST-756.pdf

[10] Heffernan, O. (2013) The Dry Facts. *Nature*, **501**, S2-S3. https://doi.org/10.1038/501s2a

[11] Demers-Bouffard, D. (2021) Climate Change Impacts: Health Effects, Vulnerabilities, and Adaptation Measures. Institut National de Santé Publique du Québec. https://coilink.org/20.500.12592/hbkdzf

[12] Ibrahima, K.K., Saïdou, M.S., Daouda, B., Idrissa, D. and Ibrahima, D. (2019) Seasonal Variability of Rainfall and Thunderstorm in Guinea over the Period 1981 to 2010. *African Journal of Environmental Science and Technology*, **13**, 324-341. https://doi.org/10.5897/ajest2019.2684

[13] Maman, I. (2022) Information agropastorale et resilience des agropasteurs de la region de tahoua au niger. *Afrique Science*, **20**, 13-22. https://www.afriquescience.net/admin/post-pdfs/a259c406a61c9e04c9e0763e07cc5b5f1720198947.pdf

[14] Masih, I., Maskey, S., Mussá, F.E.F. and Trambauer, P. (2014) A Review of Droughts on the African Continent: A Geospatial and Long-Term Perspective. *Hydrology and Earth System Sciences*, **18**, 3635-3649. https://doi.org/10.5194/hess-18-3635-2014

[15] McKee, T.B., Doesken, N.J. and Kleist, J. (1993) The Relationship of Drought Frequency and Duration to Time Scales. 8*th Conference on Applied Climatology*, Anaheim, 17-22 January 1993, 179-184. https://www.scirp.org/reference/ReferencesPapers?ReferenceID=2099290

[16] Sahani, M., Jan, M., Ine, V., Philippe, T. and Pierre, O. (2012) Evolution des caracteristiques pluviometriques dans la zone urbaine de butembo (RDC) de 1957 À 2010. *Geo-Eco-Trop: Revue Internationale de Géologie, de Géographie et d'Écologie Tropicales*, **36**, 121-136.https://hdl.handle.net/2268/156133

[17] New, M., Hewitson, B., Stephenson, D.B., Tsiga, A., Kruger, A., Manhique, A., *et al.* (2006) Evidence of Trends in Daily Climate Extremes over Southern and West Africa. *Journal of Geophysical Research: Atmospheres*, **111**, D14102. https://doi.org/10.1029/2005jd006289

[18] Nicholson, S.E. (1994) Recent Rainfall Fluctuations in Africa and Their Relationship to Past Conditions over the Continent. *The Holocene*, **4**, 121-131. https://doi.org/10.1177/095968369400400202

[19] Panthou, G., Vischel, T. and Lebel, T. (2014) Recent Trends in the Regime of Extreme Rainfall in the Central Sahel. *International Journal of Climatology*, **34**, 3998-4006. https://doi.org/10.1002/joc.3984

[20] Pettitt, A.N. (1979) A Non-Parametric Approach to the Change-Point Problem. *Ap-*

plied Statistics, **28**, 126-135. https://doi.org/10.2307/2346729

[21] Sambou, S., Dacosta, H. and Paturel, J. (2018) Variabilité spatio-temporelle des pluies de 1932 à 2014 dans le bassin versant du fleuve Kayanga/Gêba (République de Guinée, Sénégal, Guinée-Bissau). *Physio-Géo*, **12**, 61-78. https://doi.org/10.4000/physio-geo.5798

[22] Savane, I., Coulibaly, K.M. and Gioan, P. (2001) Variabilité Climatique et Ressources en Eaux Souterraines dans la Région Semi-Montagneuse de Man. *Sécheresse*, **12**, 231-237. https://www.scirp.org/reference/referencespapers?referenceid=3912631

[23] Taylor, C.M., Belušić, D., Guichard, F., Parker, D.J., Vischel, T., Bock, O., *et al.* (2017) Frequency of Extreme Sahelian Storms Tripled since 1982 in Satellite Observations. *Nature*, **544**, 475-478. https://doi.org/10.1038/nature22069

[24] Nouaceur, Z. and Muraresc u, O. (2020) Rainfall Variability and Trend Analysis of Rainfall in West Africa (Senegal, Mauritania, Burkina Faso). *Water*, **12**, Article 1754. https://doi.org/10.3390/w12061754