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Study of spatial and temporal climate variability in the Siguiri sub-basin (North-Eastern Guinea)

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Abstract

Studies on rainfall fluctuations have established periods of drought and humidity in West Africa since the 1970s. Guinea, which is one of the countries in this part of Africa, is subject to changes that lead to episodic floods and droughts. In recent years, the Siguiri area, in the north-east of the country, has suffered from climatic fluctuations that have affected the availability of groundwater resources. The methods used to verify this natural reality are diverse and consistent with those used for such studies. Climatic studies carried out in the Siguiri prefecture show that there were major breaks in the regularity of rainfall patterns in the 1980s. In the study area, dry and wet periods alternate, exposing the prefecture to rainfall deficit conditions that contribute to global warming.

Keywords: Climate; Change; Rainfall; Siguiri; Upper Guinea

1. Introduction

West Africa is exposed to variations in rainfall patterns with their corollary of rainfall breaks, floods and droughts over time. The relatively wet 1950s were followed in recent decades in West Africa by a sharp fall in rainfall **[1]; [2].** However, since the mid-1990s there has been an attempt to return to better rainfall conditions in several areas, albeit with increased inter-annual variability characterised by a sudden alternation of wet and dry years **[2].**

Faced with environmental threats, the various countries of West Africa have signed up to water resource management programs. These include the institute of the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS) and the Agro-meteorological and hydrological center (AGHRYMET), as defined by **[3].**), and take into account the results of work by authors **[2].**) on the cause-effect relationship in land degradation in the Sahel.

It is in the interest of the Republic of Guinea to be a signatory to these programs, which will help those responsible for managing water resources to develop their natural potential. It should be remembered that it has been established that in Guinea we are witnessing i) -a disappearance of the band delimited by the 2,800 mm and 2 600 mm isohyets; ii) -a southward migration of the 2 000 mm and 1 200 mm isohyets; iii) -an extension of the dry band towards the north-east of the country, during the period 1981-2010 **[6].**). Rainfall has fallen by around 31% at a temperature of 27°C. The major climatic risks are obvious: droughts (acute and recurrent), floods, which have become repetitive, and disruptions to the rainfall regime linked to early or late rainfall **[6].**).

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The aim of this study is to understand climate variation trends in the Siguiri area, which is one of the prefectures of Upper Guinea. In this study, we will try to identify the breaks in the Siguiri area with a more or less long time series, and then study the interannual and spatial variability in order to identify the areas of high rainfall (wet) and those that are more arid (dry and hot).

2. Data and methods

2.1. Presentation of the study area

The prefecture of Siguiri is in the north-east of Guinea (**Figure. 1**). The prefecture covers an area of 17,500 km², or 18.25% of the 95,884.23 km2 of Upper Guinea. The study area is located between latitudes 11° and 12°51 north and longitudes 9° and 11° west (Figure 1) and comprises 13 sub-prefectures: Siguiri centre, Kintinian, Doko, Norassoba, Niagassola, Siguirini, Kiniéba Koura, Franwalia, Maléah, Niandakoro, Naboun and Banko.

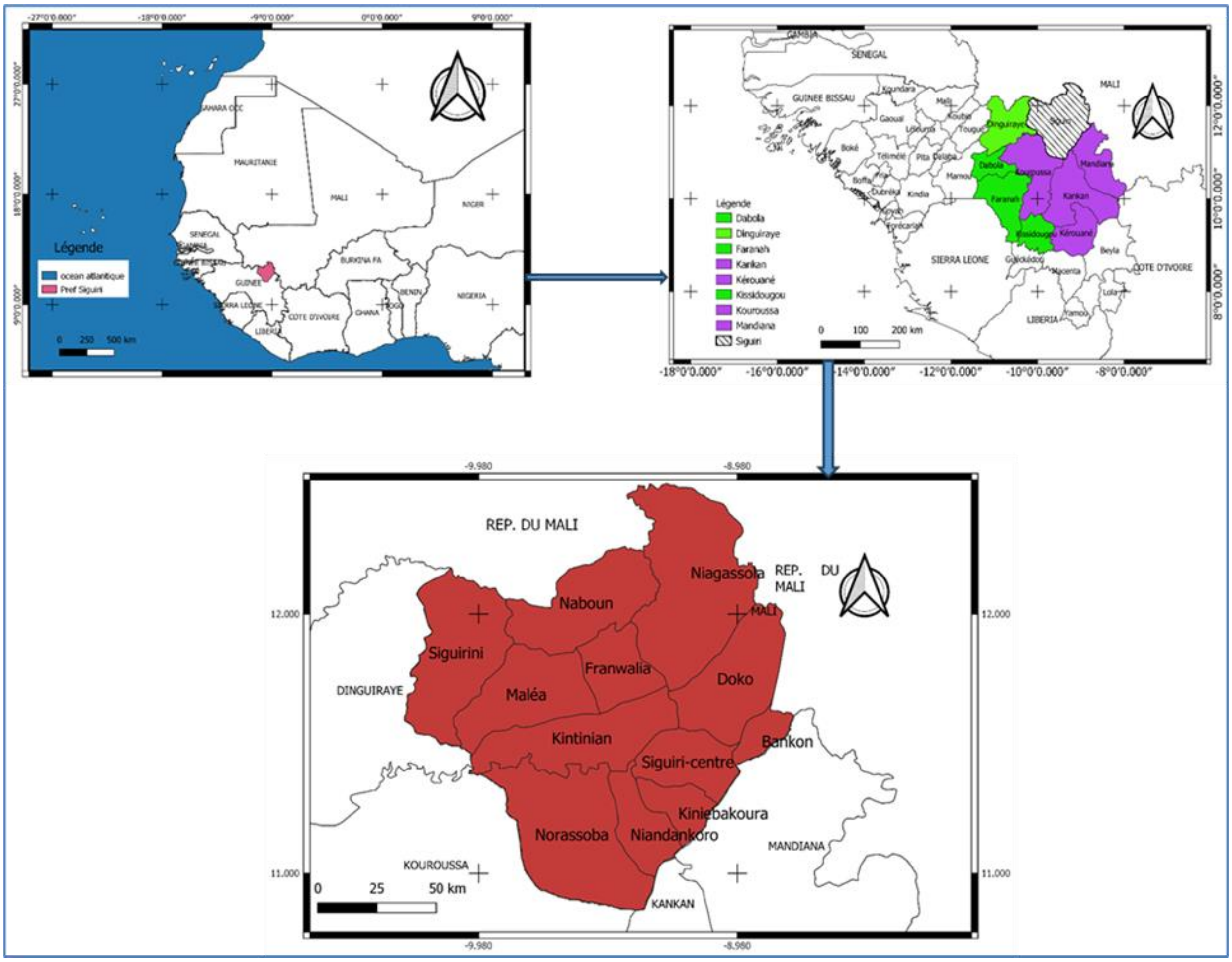

Figure 1 Location of the study area

2.2. Data

The data consists of monthly and annual rainfall data collected from the National Meteorological Office for the period 1961 to 2020. The rainfall data concern six (6) stations: Siguiri, Dinguiraye, Mandiana, Kankan, Kouroussa and Faranah in the administrative region of Upper Guinea in the north-east of the country. The rainfall data covers the period 1961-1990 for the Siguiri station and the period 1981-2020 for the rainfall stations of all the stations in question.

2.2.1. Methods for studying the spatio-temporal dynamics of rainfall

Several approaches have been used to analyse interannual, decadal and seasonal changes in climate, such as the spatial evolution of isohyets, break detection tests (Pettitt test **[7]** and Lee and Heghinian Bayesian method **[8]**) and the index method (Nicholson index, Hanning low-pass filter of order 2, drought indices). These methods are recommended by the

World Meteorological Organisation (WMO) for their convenience and effectiveness in accurately diagnosing rainfall in a zone, basin or sub-catchment **[9]; [10].**

Application of break detection tests within rainfall series

We used the statistical analysis software for time series **[11]** to detect any breaks linked to non-stationarity. The results of the tests obtained enabled us to determine the breaks in the rainfall time series.

- Pettitt Test

This consists of splitting the main series of N elements into two sub-series at each time t between 1 and N-1. The main series shows a break at time t if the two sub-series have different distributions (**[12]**; **[13]**; **[14]**. The Pettitt variable (Ut, N) is defined by **equation 1**:

$$U_{t,N} = \sum_{t=1}^{t} \sum_{t=t+1}^{N} Sgn(x_i - x_j) \quad \textbf{(Eq.1)}$$

N is the size of time series, t is the time, and the sgn is the coefficient given by the equation as follows **(Equation 2**):

$$\textbf{Sgn}=\begin{cases} +1 & if\ (x_j - x_i) > 0 \\ 0 & if\ (x_j - x_i) = 0 \\ -1 & if\ (x_j - x_i) < 0 \end{cases} \quad \textbf{(Eq.2)}$$

Under the null hypothesis, the statistic of the variable to be the test is K given as (**Equation 3**):

$$\textbf{K=Max}|U_t| \quad \textbf{(Eq.3)}$$

The exceedance probability of the k as (**Equation 4)**:

$$Prob(K_N > k) \approx 2exp\left(\frac{-6k^2}{N^2+N^3}\right) \quad \textbf{(Eq.4)}$$

When the exceedance probability is smaller than the significant level α, the null hypothesis is rejected for a significance level α **[15]**.

- Buishand Test

The Buishand test has the same hypotheses as the Lee and Heghinian test. The statistic U of the test is given as follows **(Equation 5; Equation 6)**.

$$U = \frac{\sum_{k=1}^{N-1} (S_k/\sigma_x)^2}{N(N+1)} \quad \textbf{(Eq.5)}$$

$$S_k = \sum_{i=1}^{k} (X_i - \bar{X}) \quad \textbf{(Eq.6)}$$

where Sk is the partial sum and σx is the standard deviation (calculated using **Equation (7)).**

$$\sigma_x^2 = \frac{1}{N} \sum_{i=1}^{N} (X_i - \bar{X})^2 \quad \textbf{(Eq.7)}$$

The null hypothesis stands for no break point in time series. The rejection of the null hypothesis means a break point in the time series. In addition to these different procedures, the building of a control ellipse makes it possible to analyse the homogeneity of the (xi) series **[16]**.

- Hubert Test

Hubert's segmentation procedure detects multiple breaks in the time series **[16].** The principle is to cut the time series into m segments (m > 1) such that the calculated means of the neigh boring sub-series should differ significantly. To limit the segmentation, the mean of two contiguous and the point of satisfying Scheffe's test should be different. The procedure gives the timing of the shifts. Giving a m^{th} order segmentation of the time series, ik. k = 1, ... m, the rank in the initial series of the extreme end of the kth segment (with i0 = 0), we defined the following by two equations (**Equation 8**; **Equation 9**).

$$\overline{X_k} = \frac{\sum_{i=i_{k-1}+1}^{i=i_k} x_i}{n_k} \quad \textbf{(Eq. 8)}$$

$$D_m = \sum_{k=1}^{m} \sum_{i_{k-1}+1}^{i_k} (X_i - \overline{X}_k)^2 \quad \textbf{(Eq.9)}$$

Dm is the quadratic deviation between the series and the segmentation. For a given segmentation order, the algorithm determines the optimal segmentation of a series in such a way that the deviation Dm is minimal. This procedure can also be interpreted as a stationary test where the null hypothesis of the studied series should be non-stationary. If the procedure does not produce acceptable segmentations of an order bigger or equal to two, the null hypothesis is accepted **[16]**.

The Lee and Heghinian test is based on the assumption that the series is normally distributed. The tests are Bayesian procedures based on **Equation (10**), which supposes a change in the series as follows.

$$x_i = \begin{cases} \mu + \epsilon_{i, i=1\dots,\tau} \\ \mu + \sigma + \varepsilon_i, i = \tau + 1, \dots N \end{cases} \quad \textbf{(Eq.10)}$$

where ε_i are independent and normally distributed with a mean equal to zero and a variance equal to σ^2. τ is the position in time and σ is the scope of the possible change in the mean **[16].**

Description of Khronostat Model

Khronostat **[18]** is a statistical model developed by IRD (Research Institute for Development) at the House of Water Sciences (MSE) of Montpellier. It was developed as part of a study on climate variability in West and Central Africa and is oriented on the analysis of hydroclimatic series **[17].**

Khronostat includes within it various statistical tests: i) the first test category concerns the randomness (or independence test) series (correlation test on the rank and autocorrelogram test): they carry to the constancy of the average of the series throughout its observation period and ii) the second test category concerns the homogeneous character of the series (Pettitt test, Buishand test, Hubert test, Bayesian methods or Lee & Heghinian test): they relate to the detection of breaks in a time series **[13]**).

Khronostat is adapted to all variables (climatic, hydrological and meteorological). However, it requires complete series with no gaps. Its choice in this study is justified by the robustness of its tests and also by its success through several similar studies in sub-Saharan Africa. It is also well advised by the meteorologists and climatologists over the world for surveillance or monitoring of drought.

Autocorrelogram Test

Autocorrelogram Test The estimation of the autocorrelogram is the first step in the statistical analysis of time series. The autocorrelation coefficient of order k is given by the following expression: The autocorrelation coefficient of the Kth order is given by the equation (11) **[14]** :

$$r_k = \frac{\sum_{i=1}^{N-k}(X_i - \bar{X}_1)(X_{i+k} - \bar{X}_2)}{\sqrt{\sum_{i=k}^{N-k}(X_i - \bar{X}_1)^2 \sum_{i=1}^{N-k}(X_{i+k} - \bar{X}_2)^2}} \quad \textbf{(Eq.11)}$$

The averages $\bar{X}_1$ and $\bar{X}_2$ are determined for each value of k by equations (12) and (13)

$$\bar{X}_1 = \frac{1}{N-k} \sum_{i=1}^{N-k} X_i \quad \textbf{(Eq.12)}$$

$$\bar{X}_2 = \frac{1}{N-k} \sum_{i=k+1}^{N} X_i \quad \textbf{(Eq.13)}$$

The graph rk=f(k) represents the auto correlogram. The series is called random when, for large N, the autocorrelation coefficient rk, has a value close to zero for all values of k nonzero **(Figure 14)**.

$$-\frac{u_{\left(1-\frac{\alpha}{2}\right)}}{\sqrt{N}} < r_k < \frac{u_{\left(1-\frac{\alpha}{2}\right)}}{\sqrt{N}} \qquad \textbf{(Eq.14)}$$

U is the standard normal variable obtained from the Student table with one degree of freedom N-2. The series is considered random if all or most of rk values are within the confidence interval of the autocorrelogram.

Correlation Test of Ran

The correlation test in the row to determine the number of pairs of Xi and Xj such as Xj > Xi, for j> i. Under the null hypothesis H0 «the series is random» for a given level of significance α = 5% . The standard score U is given by equation15 **[18]**.

$$U = \frac{r^*}{\sqrt{var\ (r^*)}} \qquad \textbf{(Eq.15)}$$

The test is based on the statistical defined by equation (**Equation 16**):

$$r^* = \frac{4N_C}{N(N-1)} - 1 \qquad \textbf{(Eq.16)}$$

In this expression, Nc represents the number of pairs of consecutive observations (X_i, J_i) as

$$X_j > X_i\ j > i; with\ (i = 1, j = 2, N), (i = 2, j = 3, N), \dots (i = N-1, J = N) \qquad \textbf{(Eq.17)}$$

The variance (r^*) var r is given by the relation (7) **[17]**:

Under the null hypothesis of a random series, the reduced centred variable U tends to follow a normal distribution when N increase. The null hypothesis is accepted when we have

$$U_{\frac{\alpha}{2}} < U_{1-\frac{\alpha}{2}} \qquad \textbf{(Eq.18)}$$

In the case of a tail test, the null hypothesis is accepted when:

$$|U| < U_{1-\frac{\alpha}{2}}$$

With $U_{1-\frac{\alpha}{2}} = 1.96$ for a sample size (N> 30)

When the series is not random, it can admit a tendency or a periodicity

Application of the isohyet method (iso values)

The application of the isohyet method is based on the tracing of lines of the same monthly and annual rainfall from the rainfall values acquired at the sub-basin stations and that of neigh boring prefectures. The isohyet plot is not unique because it takes into account the variation in geographic, topographic and precipitation coordinates, rainfall stations considered within the limits of the watershed. The semi-automatic representation of isohyets in plan is carried out using the Surfer software 13 software.

The precipitation Pmoy is calculated by expressions 19 and 20 **[19]**.

$$P_{moy} = \frac{\sum_{i=1}^{n}(S_i)(\bar{P}_i)}{S} \qquad \textbf{(Eq. 19)}$$

$$\bar{P}_i = \frac{P_i + P_{i+1}}{2} \qquad \textbf{(Eq. 20)}$$

With: **Si**: influence surface of rain gauge I in km^2

Pi: Precipitation at the post in mm

S: Area of the watershed in km^2.

$\overline{P}_i$

Average precipitation between 2 isohyets in mm

Climatic deficits

The deficit of the dry period, compared with the wet period, is evaluated by applying the formula represented by equation 21:

$$D = \frac{XJ}{Xi} - 1 \quad \textbf{Eq. (21)}$$

with

D: the hydroclimatic deficit

Xj: the average over the period after the break

Xi= the average over the period before the rupture

Calculation of the Nicholson rainfall index

This index is used to measure the deviation from the average established over a period, based on data from the stations in question. The annual rainfall index is defined as a reduced centred variable. It is obtained by equation 22 **[20].**

$$I_P = \frac{x_i - x_m}{\sigma} \quad \textbf{Eq. (22)}$$

With:

Xi: value of annual rainfall (or annual discharge) in year i ;

Xm: interannual mean value of rainfall (or annual discharge) over the period studied;

σ: the standard deviation of the interannual rainfall (or annual flow) over the period studied;

Ip: rainfall index.

The rainfall index reflects a rainfall surplus or deficit for the year under consideration compared with the reference period

2nd order Hanning low-pass filter or weighted moving average method

This method eliminates seasonal variations in a given time series. Weighted rainfall totals are calculated using equations 23; 24; 25; 26 and 27 recommended by the author **[21].**

$$X(t) = 0{,}06x_{(t-2)} + 0{,}25x_{(t-1)} + 0{,}38x_{(t)} + 0{,}25x_{(t+1)} + 0{,}06x_{(t+2)} \quad \textbf{Eq. (23)}$$

$$X_{(1)} = 0{,}54X_{(1)} + 0{,}46X_{(2)} \quad \textbf{Eq. (24)}$$

$$X_{(2)} = 0{,}25X_{(1)} + 0{,}5X_{(2)} + 0{,}25X_{(3)} \quad \textbf{Eq. (25)}$$

$$X_{(n-1)} = 0{,}25X_{(n-2)} + 0{,}5X_{(n-1)} + 0{,}25X_{(n)} \quad \textbf{Eq. (26)}$$

$$X_{(n)} = 0{,}54X_{(n)} + 0{,}46X_{(n-1)} \quad \textbf{Eq. (27)}$$

Where n denotes the size of the series.

The centred and reduced indices of the weighted annual rainfall heights obtained are calculated to better distinguish between periods of rainfall deficit and surplus.

Calculation of drought indices

The SPI is an index for measuring meteorological drought. It is a probability index based solely on precipitation.

The probabilities are standardised so that an SPI of 0 indicates a median amount of precipitation (compared with an average reference climatology, calculated over 30 years). The index is negative for drought and positive for wet conditions **[22]**.

The standardised precipitation index (SPI) is given by formula 28.

$$\textbf{SPI}=\frac{(P_{i-P_m})}{\sigma} \quad \textbf{Eq.(28)}$$

where Pi : rainfall in month or year i

Pm: the mean rainfall of the series over the time scale considered

σ: the standard deviation of the series over the time scale in question

The SPI can be calculated for different time scales and can provide an early warning of drought. Drought conditions are established by the authors **[23]** and **[24]** in **Table 1**. Negative annual values indicate drought and positive values indicate wet conditions.

Table 1 Classification criteria for drought indices [23]; [24]

Classes	Degree of dryness
ε>2	Extreme Humidity
1 <ε<2	High humidity
0<ε<1	Moderate Humidity
-1<ε<0	Moderate dryness
-2<ε<-1	Severe drought
ε<-2	Extreme dryness

To open discussions on the general climatic trends in the Siguiri area we determine the UNCCD aridity indices **[25]** classifying from 0.05 to 0.65 into hyper arid, arid, semi-arid and subhumid zones (**Wade, 2016**). According to Wade **[25]** by the Lang factor established by the relationship Fp = P mm / T°C), the De Martonne method by I = P (mm)/ (T°C + 10), the bioclimatic indices by I = ETR / ETP*100) of Le Borgne (1988) from wade **[25]**, the MAB aridity index of **UNESCO (1979**) which uses the relationship (IA= P/ETP), of UNEP, 1997 in **Wade article [25]** by the ratio AI= (P mm / ETP mm).

3. Results

3.1. Analysis of rainfall variability

3.1.1. Identification of breaks in the 1961-2020 rainfall series

The break tests applied are A.N. PETTITT (1979), U statistics by T.A. BUISHAND (1982, 1984), procedure by A.F.S. LEE and S.A. HEGHINIAN (1977), segmentation method by HUBERT (J.P. CARBONNEL and P. HUBERT, 1985; P. HUBERT and

J.P. CARBONNEL, 1987). Table II shows the general variation in rainfall patterns in the Siguiri area over the period 1961-2020 (**Table 2).**

At the end of the studies, conclusive results were obtained on the variability of rainfall amounts in recent years. According to the break tests required for such studies: i) -for the 1961-1990 period, the break occurred in 1982. The average rainfall before the break (1961-1982) is 1290.2 mm, whereas the average rainfall after the break (1983-1990) is 1060.54 mm, i.e. a deficit of 18% compared with the average rainfall of 1229.5 mm for the period 1961-1990. ii) - for the period 1991-2020, the breaks occurred in 1991, 1993, 2001, 2007 and 2018. The rainfall deficit over the period.

1991-2020 is estimated at 12%. For all periods (1961-1990 and 1991-2020), the shortfall averages 16% compared with normal rainfall over the last 60 years, i.e. 1961-2020.

Table 2 General variation in rainfall patterns at the Siguiri prefecture station (periods: 1961-1990; 1991-2020)

Period	**Breakdown dates according to**				**Variation in average rainfall**		
	PETTITT	LEE ET HEGHINIAN	HUBERT	Dates	Average before breakage (mm)	Average after breakage (mm)	Deficit (%)
1961-1990	1982	1982	1982	1961-1982	1290.91	-	19
				1983-1990		1060.54	
Average for the 1961-1990 period							19
1991-2020	1991	1991	1991	1991	1269.1	1269.1	0
	1993	1993	1993	1992-1993	1026.5	-	
	2001	2001	2001	1994-2001	-	1235.8	+20
	2007	2007	2007	2002-2018	1230.2	-	
	2018	2018	2018		2019-2020	1167.2	5
Average for the period 1991-2020							12
Overall average							16

3.1.2. Detection of breaks in the 1981-2020 rainfall series

Rainfall over the period 1981-2020 is marked by irregularities in these successive climatic periods. The break years occurred for the deficit periods between 1981-1993; 1998-2002 and between 2013-2020. The deficit recorded in the variation in average rainfall is estimated at 14%. All the tests agree that the break occurred in 1989 (**Table 3**) and (**Figure 2**).

Table 3 Breaking dates in the rainfall series for the period 1981-2020 and relative percentage change in the study area.

Station	**Breaks according to**			**Variation in average rainfall**			
	PETTITT	LEE ET HEGHINIAN	HUBERT	Date of break	Average before break (mm)	Average after break (mm)	Deficit (%)
Siguiri	1989	1989	1989	1989	1 068.54	1217.56	14 %

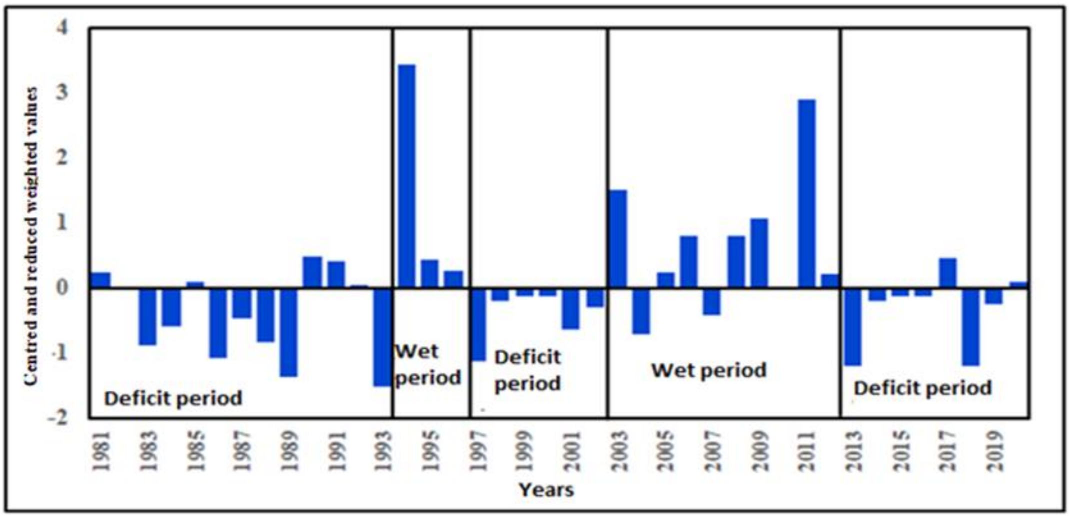

Figure 2 Interannual rainfall trends at Siguiri (centred indices reduced)

The representation of Nicholson indices in **Figure 3** shows that there has been a succession of deficit (dry) periods and wet (surplus) periods. To understand the return of climatic conditions in the study area, the moving curves of the weighted indices show the alternation between periods of high rainfall and low rainfall.

Between 1981 and 1993, there was less rainfall than in the years between 1961 and 1980, when average rainfall was 1298.98 mm. The average rainfall for this period was 1094.376 mm. The year 1992 was marked by abundant rainfall compared with the following years, with an average annual rainfall estimated at 1190.9 mm, while between 1998 and 2002, the average annual rainfall was 1343.97 mm. The return of high rainfall between 2003 and 2012, with an average annual rainfall of 1318.96 mm, was followed by a period of deficit from 2013 to 2020, with an average annual rainfall of 1117.2 mm **(Figure3).**

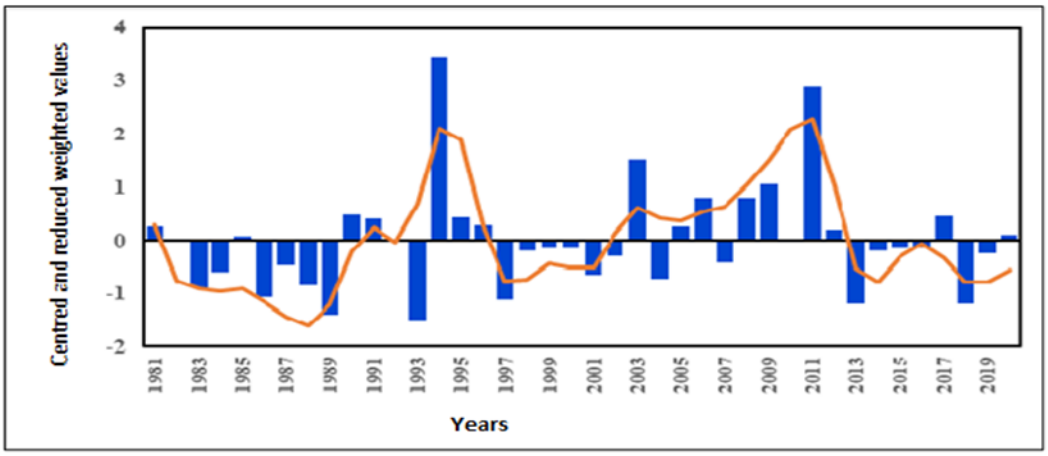

Figure 3 Interannual change in rainfall at Siguiri (weighted, centred and reduced values)

3.1.3. Spatial variability of rainfall in the study area

The statistical data for rainfall values obtained over the years are shown in **Table 4.** The displacement of isohyets defines the prevailing rainfall conditions in a given region. This displacement is highly dependent on natural geographical (altitude, latitude) and climatic (temperature, atmospheric pressure) conditions. The rainfall statistics for the normal rainfall period 1981-2020 include a maximum value of 1,912 mm and a minimum value of 862.2 mm for an average annual rainfall of 1,184.0325 mm.

Table 4 Statistical elements of the decennial annual rainfall in the study area for the period 1981-2020

Parameters	Period: 1981-1990	Period: 1991-2000	Period: 2001-2010	Period: 2011-2020
Minimum (mm)	888.2	862.2	1011.7	931.9
Average (mm)	1090.5	1215.8	1219.02	1196.6
Maximum (mm)	1287.8	1912.0	1543.5	1799.1
Standard deviation	132.15	279.28	189.73	240,.76
Coef. Variation (%)	12 %	23 %	15%	20 %

Between 1981 and 1990, rainfall was persistent and uniform throughout the Siguiri area (**Figure 4**). Rainfall amounts vary between 800 and 1 200 mm, with an average of 1090.5 mm. From the north-east to the centre of the study area, rainfall decreases from less than 1 050 mm to less than 1 300 mm. The variation in rainfall associated with the shift in isohyets from 862.2 to 1912.0 mm can be seen on the map for the period 1991-2000. During this decade, major rainfall events in excess of 1 300 mm occurred in the south-west and west of the study area. From 2001 to 2010, rainfall amounts increased from a minimum of 1031.8 mm to a maximum of 1505.2 mm, with an average of 1233.3 mm. The north-east and south-east remain areas where rainfall amounts are below 900 mm, while in the south-west rainfall amounts exceed 1000 mm. In terms of rainfall amounts, the period 2011-2020 is a period in which rainfall amounts have increased compared with the previous decade. The minimum rainfall is estimated at 931.9 mm, compared with a maximum of 1 799.1 mm and an average rainfall of 1 196.6 mm. Rainfall of over 1 500 mm was recorded in the south-west, in contrast to the north-east and south-east, where isohyets were below 1 500 mm.

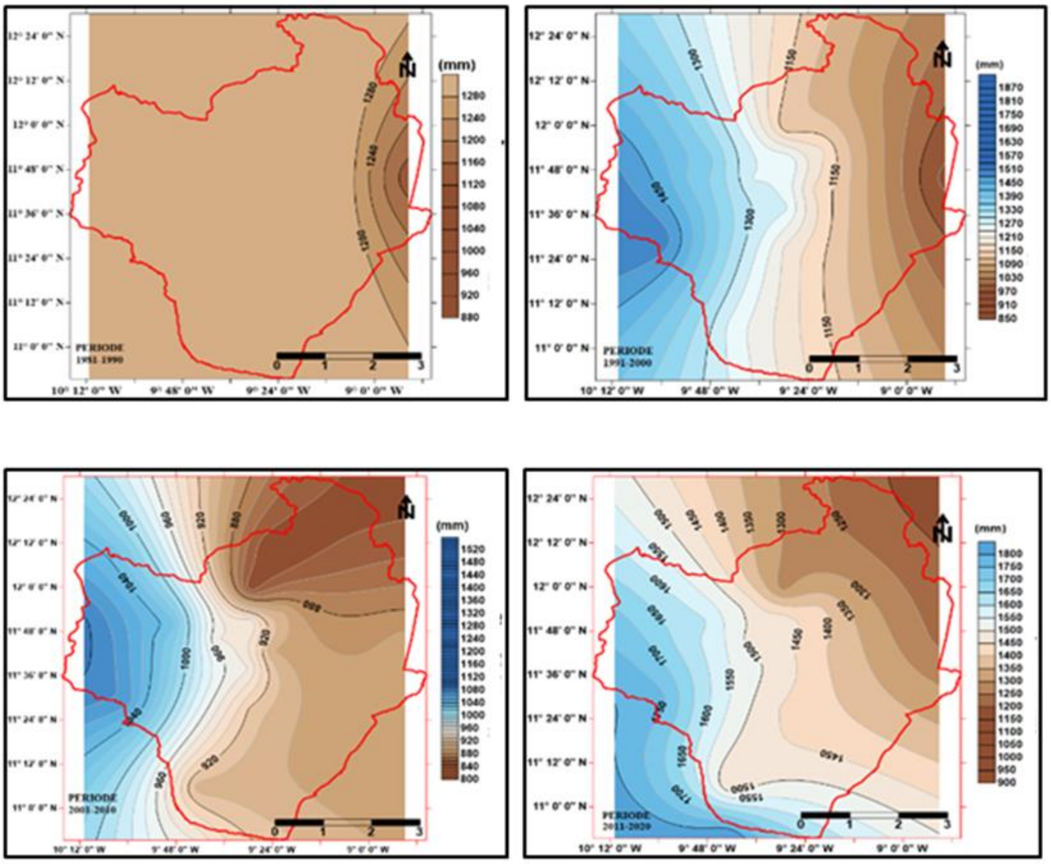

Figure 4 Spatial and temporal decadal dynamics of isohyets in Siguiri (1981-2020)

By compiling all the isohyet maps, we can divide the Siguiri area (**Figure 5**) into two main areas: the eastern part, where isohyets range from 800 mm in the east to 1300 mm in the centre, and the western part, where isohyets range from over 1300 mm to over 1500 mm of annual rainfall.

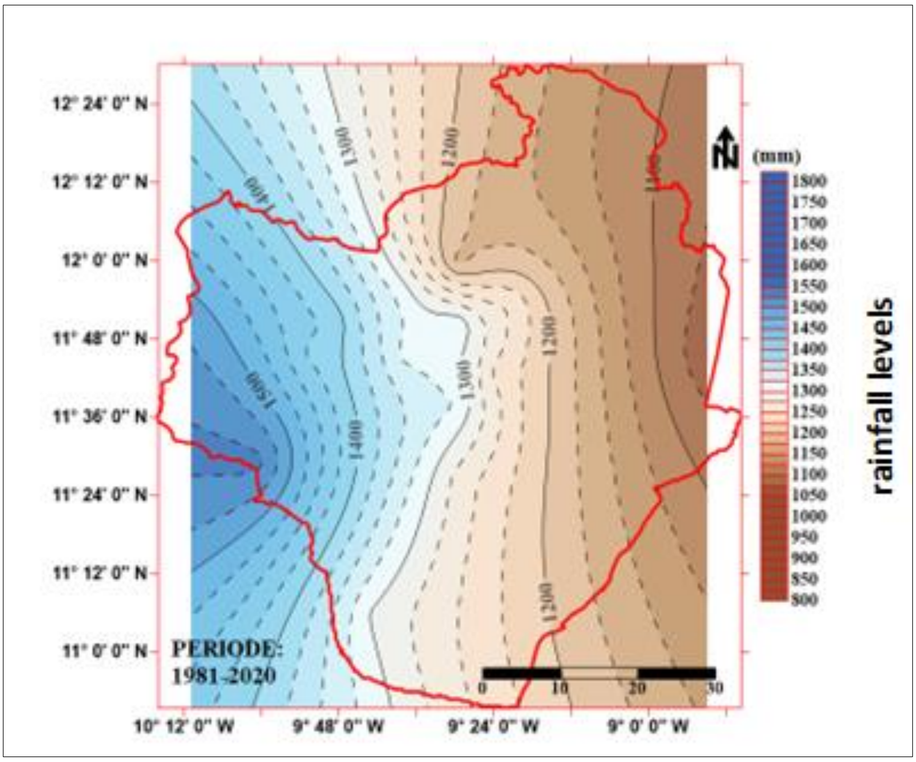

Figure 5 Summary map of isohyets in Siguiri (1981-2020).

3.1.4. Analysis of rainfall indices

Rainfall during the period 1981-2020 is marked by irregularities in these successive climatic periods (**Table 5**). Deficit years occurred between 1981-1993, 1998-2002 and 2013-2020. The wet periods are between 1994-1997 and 2003-2012. Deficits are determined for each period. They are 15% and 16% for the 1981-1993 and 1998-2002 periods. A 15% deficit is established for the 2013-2020 period.

Table 5 Variation in averages before and after the rain breaks

Period	Average before the break in rainfall	Average after rain break	variation	Déficit
1981-1993	1298.98	1094.38	-204.60	15 %
1994-1997	1094.4	1343.975	249.60	
1998-2002	1344.00	1126.26	-217.7	16 %
2003-2012	1126.26	1318.96	192.7	
2013-2020	1318.96	1117.2	-201.76	15%

3.1.5. Cartographic representation of rainfall drought indices

The maps of rainfall indices from 1981 to 2020 are made up of humidity variation maps and temperature variation maps shown in **Figures 6 and 7**. They are based on annual decadal data: 1981-1990; 1991-2000; 2001-2010; 2011-2020. Analysis of the variations in climatic parameters (rainfall, humidity, temperature) indicates that the study area is under the constant influence of variations in dry and rainy spells.

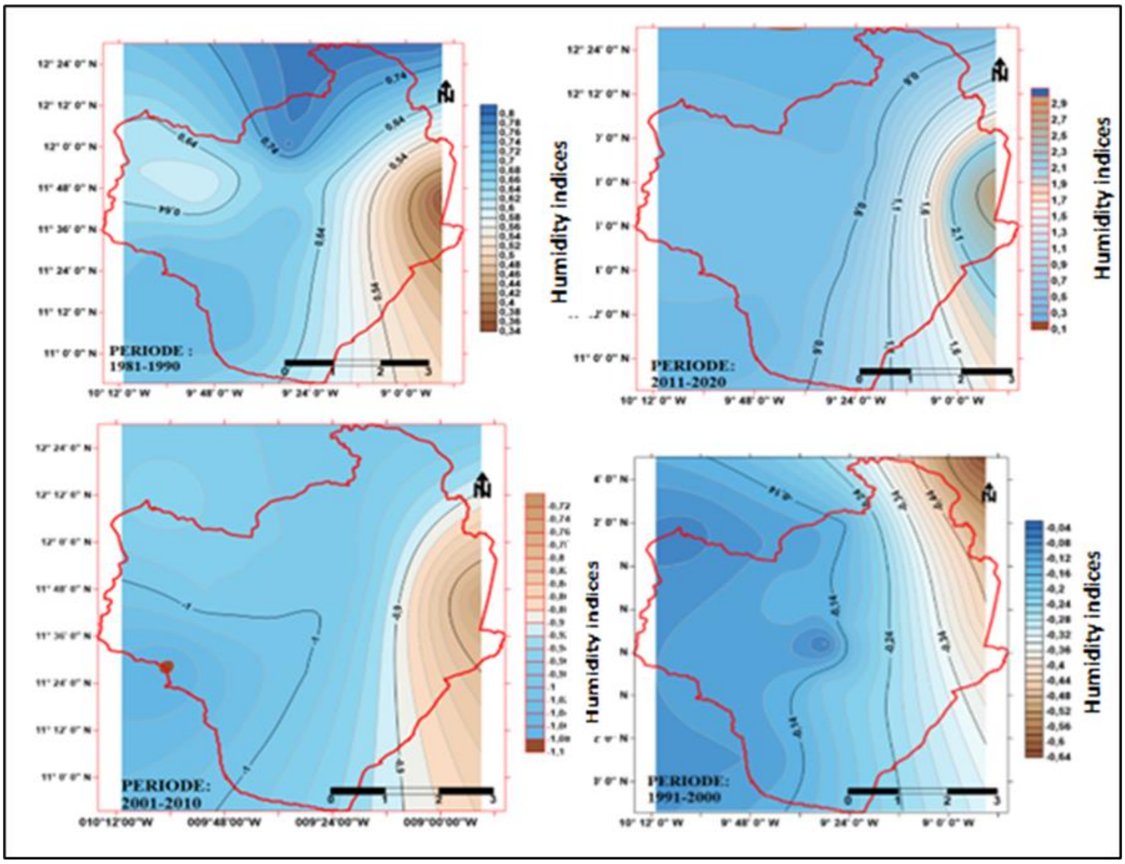

Figure 6 Spatial evolution of decadal humidity indices from 1981 to 2020 in Siguiri

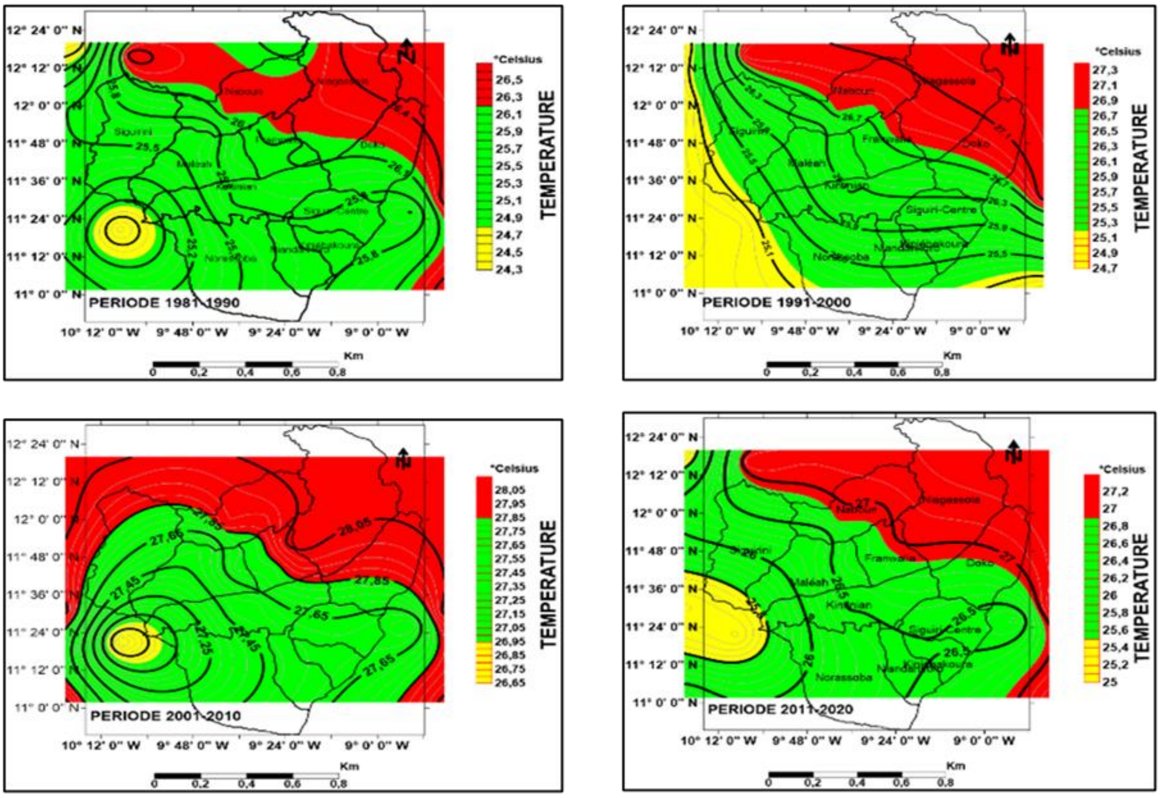

Figure 7 Spatial and temporal variations in annual ten-year temperatures in Siguiri from 1981 to 2020

The UNCDD aridity index (I) **(Bied-Charreton, 2012** in **Wade [25]**) equals 1.11, designating the Siguiri area as sub-humid dry. Such a zone is characterised by an almost permanent rainfall deficit linked to high evapotranspiration, high daytime temperatures, low air humidity leading to annual water deficits **[25].** The index calculated using Lang's factor is 1.77, corresponding to an arid climate. The De Martonne (1923) method in **Wad**e document **[25]** gives a value equal to 33.19, characteristic of a cold temperate or tropical climate, while the water balance of the bioclimatic indices of Le Borgne (1988) in **Wad**e **[25]** gives an arid zone for the prefecture of Siguiri for I= 1.08. The UNESCO MAB Programmes (1979) in **Wad**e **[25]**, I has for 1.11 (subhumid to humid climate) and UNEP (UNEP, 1997 in **Wad**e **[25]** indicating 1.11 is significant wetland for the prefecture of Siguiri.

4. Discussion

This study shows that the rainfall regime in the area has declined significantly in recent years (1980-2020). This is reflected in a shift in isohyets in the Upper Guinea region from north to south.The methods used to verify and study rainfall variation trends in the Siguiri area are interesting. They revealed that the climate changes reported in West Africa are also being felt in Upper Guinea, and specifically in the Siguiri area. This area, located in the extreme north-east of Guinea, is much more affected by drought. While the southern and western parts of the study area remain rainy, rainfall patterns have varied considerably in this part of Guinea.

Under current conditions, the rainy season is reduced to 3 months (June, July and August) instead of 4 (May, June, July and August), in favour of the dry season, which comprises 8 months (September, October, November, December, January, February, March and April), with May being considered as an intermediate month between the dry and rainy seasons. In the study area, the warm wind blowing from the north-east could be felt in the south-western part of the area, influencing the climatic parameters. The increase in dry surfaces should cause A rise in air temperatures through heat transfer.

According to **Sultan [26]**the reduction in forest cover may contribute to an increase in the atmospheric content of greenhouse gases. With reference to 1961-1990 climate normals, cumulative rainfall was in surplus from 1950 to 1980 and in deficit from 1981 to 1994 at the three stations studied. Between 1994 and 2015, there was an overall deficit at the Siguiri and Kankan stations, but a surplus at Faranah **[27].** Atmospheric and climatic parameters strongly influence the spatiotemporal distribution of rainfall (Alamou et al., 2016). The results of the study show a downward trend in rainfall variables and relative humidity in the eastern part of the Siguiri area.

Based on the results of the DNM study, the north-eastern part of Siguiri suffers much more from drought than the southern and western parts, which have excess and normal rainfall. The desert is advancing as a result of the intensification of mining activities (industrial and small-scale) in this north-eastern part of Siguiri, which borders on the Republic of Mali. In terms of the number of rainy days, the north-eastern part recorded a difference of 3 days in 2019 compared with 2018 at the same period **[28].** This study shows that the rainfall pattern in the area has declined significantly in recent years (1980-2020). This is reflected in a shift in isohyets in the Upper Guinea region from north to south. In this area, the rainfall anomaly compared with the normal (1981-2010) varies from -30 to -20%. This rainfall anomaly, established and compared with the results of a recent study of the rainfall situation in 2019 and 2018, shows that the anomaly is worsening, with a difference of -10 to -70%.

These various changes in the study area were reported by Gautier **[29])** in their study of variability in non-Sahelian West Africa (1950-1989). According to the results of the study by Kouassi **[30]** changes in isohyets effectively began in 1970. In the 1950s and 1960s, cumulative rainfall could reach 1600 mm in the study area. In the 1970s and 1980s, recorded isohyets varied from 1400 mm to 1200 mm. In the last decade of 2010, isohyets remained at 1200 mm. The signs of climate change are quite remarkable in view of the results obtained in this study. The study shows that since 2010, the general rainfall trend has been downwards compared with the average rainfall recorded. The warming that prevailed strongly from 1980 to 1990 is continuing today, with its corollary of changes in rainfall patterns **[6].** These studies show that the variability of seasonal rainfall patterns depends, on the one hand, on the fall in relative humidity and, on the other, on the rise in air temperature and the influence of the climate in North Africa, which is experiencing increasing desertification, as shown by the studies of **Diarra [31].** This phenomenon of increasing scarcity and disruption of rainfall in the study area dates back to 1970 and is moving from the north of Africa towards the south-west, and does not seem to be stopping, given the results of work by Nicholson **[1], [32]** and **[12]).**

5. Conclusion

Analysis of the isohyets and drought indices shows that they have changed over time. Thus, when we follow the rainfall iso-values in millimetres from the north-east and south-east to the west and south-west of the study area, we see that they vary differently from east to centre and south-west. The eastern part of the area is less rainy than the western and south-western parts. The drought indices indicate hot, dry areas in the north-east, while the central and western parts of the zone are wet.

The tests used to identify the break periods are limited to the deficit periods between 1981-1993, 1998-2002 and 2013-2020, and the break year for the methods used is 1982 for the 1961-1990 rainfall normal. When it comes to the period 1981-2020 for the period identical to the rainfall station networks considered, the Hubert and Nicholson segmentation study indicates 1989 as the break year. However, it should be noted that the rainfall breaks occurred in the 1980s.

After compiling all the decadal isohyet maps for the 1981-2020 rainy period, we have divided the Siguiri area into two main areas: the eastern part, where isohyets vary from 800 mm in the east to 1300 mm in the centre, and the western part, which has isohyets varying from more than 1300 mm to more than 1500 mm of annual rainfall. These periods of rainfall variation show an average deficit of 14%. Over the last 60 years, the deficit has averaged 16% compared with the various rainfall normals.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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