Hydrology
2017; 5(4): 41-57
http://www.sciencepublishinggroup.com/j/hyd
doi: 10.11648/j.hyd.20170504.11
ISSN: 2330-7609 (Print); ISSN: 2330-7617 (Online)

Rainfall Variability and Water Supplies in the Diarha Watershed (Tributary of Gambia River)

Ibrahima Thiaw

Department of Geography, Laboratory of Hydrology and Morphology, University Cheikh Anta Diop, Dakar, Senegal

Email address:
biwaith@hotmail.fr, thiawibrahim1@gmail.com, ibrahima4.thiaw@ucad.edu.sn

To cite this article:
Ibrahima Thiaw. Rainfall Variability and Water Supplies in the Diarha Watershed (Tributary of Gambia River). *Hydrology*. Vol. 5, No. 4, 2017, pp. 41-57. doi: 10.11648/j.hyd.20170504.11

Received: August 2, 2017; **Accepted**: August 21, 2017; **Published**: October 13, 2017

Abstract: The present study consisted of analyzing the spatial and temporal variability of the rainfall series in the Diarha watershed between 1921 and 2014, using the Nicholson indices, the stationarity tests and the Thiessen polygons method for spatial analysis, to quantify surface water supplies and to determine the impact of this rainfall variability on the hydrology of the basin. The results show that the rainfall series are not stationary. They show breaks between 1965 and 1979 (with 1967 as the year of rupture for 6 of the 10 stations in the basin). From this break-up period (1967) to the present day, average annual rainfall decreased by 10.5%. On a monthly basis, it appears that precipitation decreased significantly for almost every month between the two periods. On a daily basis, the analysis of the daily rainfall fractions reveals a tendency to decrease the average annual rainfall over 40 mm (which are considered to be the heavy rains) from years of rupture. At the spatial scale, the variability of annual precipitation is marked by a translation of isohyets towards the South from the decades 1971-1980 and 1981-1990. During this period, the decline in rainfall resulted in a shift of the isohyets towards the south in the less rainy zone in the north (in the South Sudanian domain); while the latter are tightening in the "strong" precipitation zones which are located in the South (in the Guinean climate domain) and in the Center-east of the basin. On the other hand, a slight trend of rainfall recovery is noted during the decades 1991-2000 and 2001-2010. At the same time, the flows of the Diarha vary from one year to another according to the precipitated water slides on the basin and the ETP. To this must be added the influence of pedology and geology (the river flowing over the Proterozoic and Paleozoic formations of the Birrimian basement), but also of the high topography of the basin, in this case the relief and its slope system. All these factors combine in space and time to allow for high values of basin runoff.

Keywords: Diarha, Rainfall, Rupture, Variability, Water Supplies, Watershed

1. Introduction

Water, by its nature and importance, by its functions and uses, has become a scientific, economic, social and even political concern of the international community. Challenges related to water have finally placed it at the center of the global problem related to the development of humanity, the survival of ecosystems, the future or the future of planet earth [1]. Awareness and then mobilization around this vital resource is justified by its vulnerability exacerbated today by a number of factors, the main ones being: global change and hydro-rainfall variability.

In Senegal, this irregular rainfall variability has been observed since the 1970s [2, 3]. This variability of inputs results in a significant reduction in water availability and results in an annual migration of isohyets to the south [3]. However, South-eastern Senegal is the region that has the greatest rainfall, the largest water resources in Senegal in the Faleme and Gambia basins [4]. It is in this context that the Gambia River basin, with its 77,054 km², has been the subject of several studies: hydrological [5], climatological [6, 7], soil and geomorphological [8] studies. The interest shown for the knowledge of the water resources of these zones of strong water potential, led us to carry our study on one of the tributaries of left bank of the River Gambia: the watershed of the Diarha.

The Diarha watershed extends in latitude between 12° 15’ and 12° 40’ north and between 12° 20' and 13° West longitude. It lies between two states: the Republic of Guinea to the south, to latitude 12° 25’ North, represents 57% of the basin, and the Republic of Senegal to the north, which occupies 43% of the basin. The basin is wider in the South than in the North.

The Diarha watershed is not immune to climate problems in the intertropical zone in general and Senegal in particular since 1970. These problems include rainfall deficits and shrinkage of the season has significantly modified their hydrological regime, affecting at the same time the flow in the basin. The great drought that has struck the Sahel on a long-term basis since 1970 remains an edifying example. In addition to the hydro-rainfall deficit and its impact on agriculture and the economy, this drought has resulted in an awareness of the need to control and manage existing water resources as well as possible. The result is the elaboration or reactivation of major water resource development projects to preserve agricultural activities from the vagaries of the climate. However, the success of such projects necessarily involves a prerequisite: a good knowledge of precipitation and the resulting water intakes. It is with this in mind that this study is aimed at improving the knowledge of the rainfall in the spatial and the punctual of the watershed of the Diarha and know the contributions of surface water, surface waters largely undervalued and recovered in Senegal

2. The Study Area

The Diarha catchment at the road bridge with an area of 759.3 km² and a perimeter of 145.1km is a tributary of the left bank of the Gambia River.

The basin is equipped with a single hydrometric station which was commissioned in May 1972. This station is located at the road bridge on the Kaldé-Salemata departmental at 12° 35' North latitude and 12° 46' West longitude.

Climatically, the Diarha watershed straddles two climatic domains: the South-Sudanian climatic domain in the North and the Guinean climate domain in the South. Its climate is influenced by the West African monsoon, with an irregular and variable rainy season (7 to 8 months) and a short dry season (4 to 5 months). On a monthly basis, July, August and September account for 73% of annual rainfall.

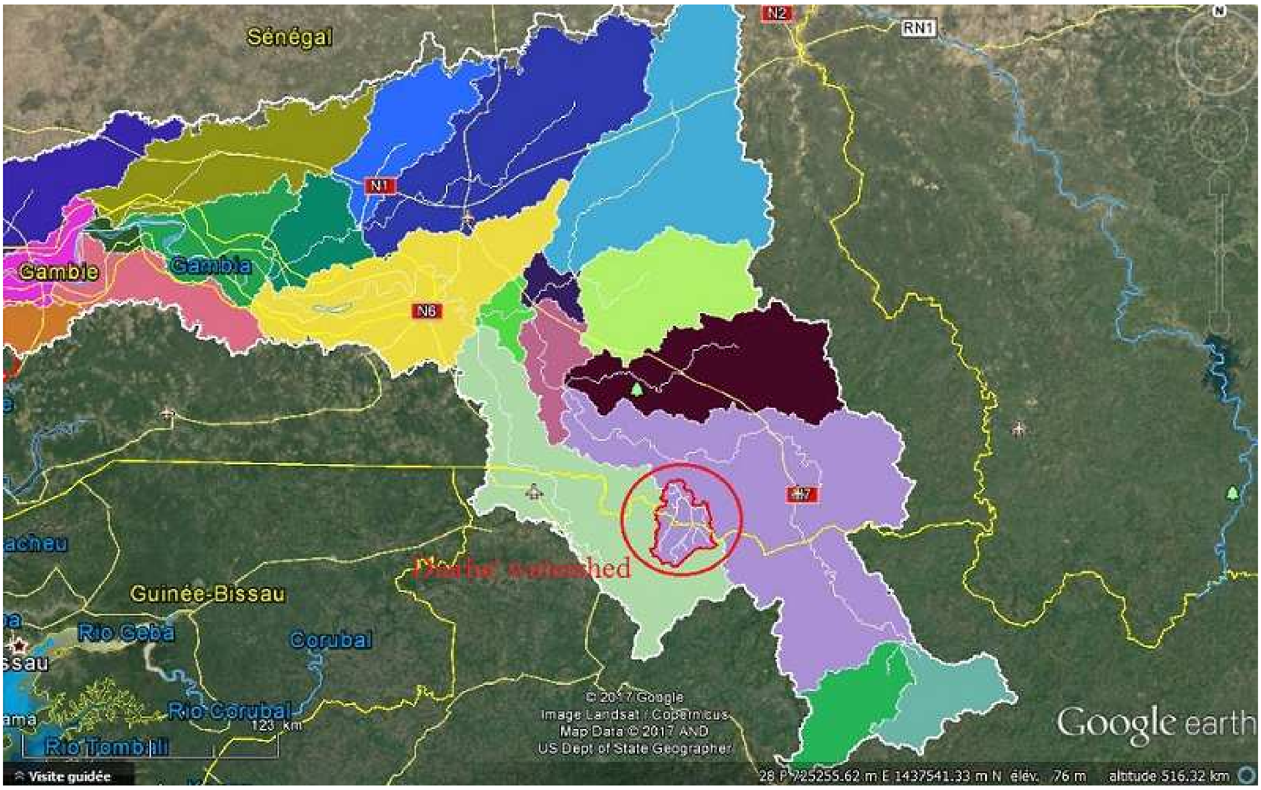

Figure 1. Location of the Diarha in the Gambia River catchment area.

2.1. Geology and Hydrogeology

The geological history of the Diarha catchment reflects that of Kedougou and the African continent, "country of old platforms" where ancient sedimentary formations traversed by volcanic rocks have been heavily folded, metamorphosed and injected with granitic rocks [8]. The basin covers complex and diverse geological formations. During the Infracambrian, the Cambrian and the Ordovician deposited thick sedimentary series, mainly sandstone. These sedimentary series are affected by folds and crossed by very thick doleritic outcrops. These sandstones and dolerites form the principal reliefs of the Diarha basin.

On the whole, the geological formations encountered in the Diarha basin, especially sandstones, schists, quartzites, pelites and dolerites, are of very low permeability, mainly due to lateritic overlay and physico- Chemical rocks that eventually turn into clays.

2.2. Topography

The terrain and its slope system determine the suitability of the land for drainage. They represent the different classes of altitudes of the basin and largely influence the hydrological behavior of the basin and the velocity of water from upstream to downstream. The 3-Dimensional (3D) digital terrain model shows the different relief units in the basin and shows the position of the valleys in relation to the highlands (figure 2). The blue colors correspond to the lowlands, with altitudes varying between 100 and 120 m. The green colors correspond to the slope of connection with altitudes varying between 150 and 350 m. Red and yellow correspond to "mountainous" areas with altitudes ranging between 350 and 600 m.

Like the relief, the slopes of the Diarha basin are very important. They vary between 2.34° and 42.72°. The highest slopes are located in the southern part of the basin and in the northwest, where they vary between 5.52° and 19.93°. These slopes are at the level of the connecting slopes, the transit zone between the mountainous areas (Mount Bassaris, and the northern part of the Fouta Djallon massif), and the lowland areas. The lowest slopes vary between 2.34° and 5.52° and occur in the center and east of the basin. In this part of the basin, the absence of significant level differences slows down the speed of the flows and the propagation time. The slope 42, 72° is much localized in particular along the northern barrier of the Fouta Djallon foothills.

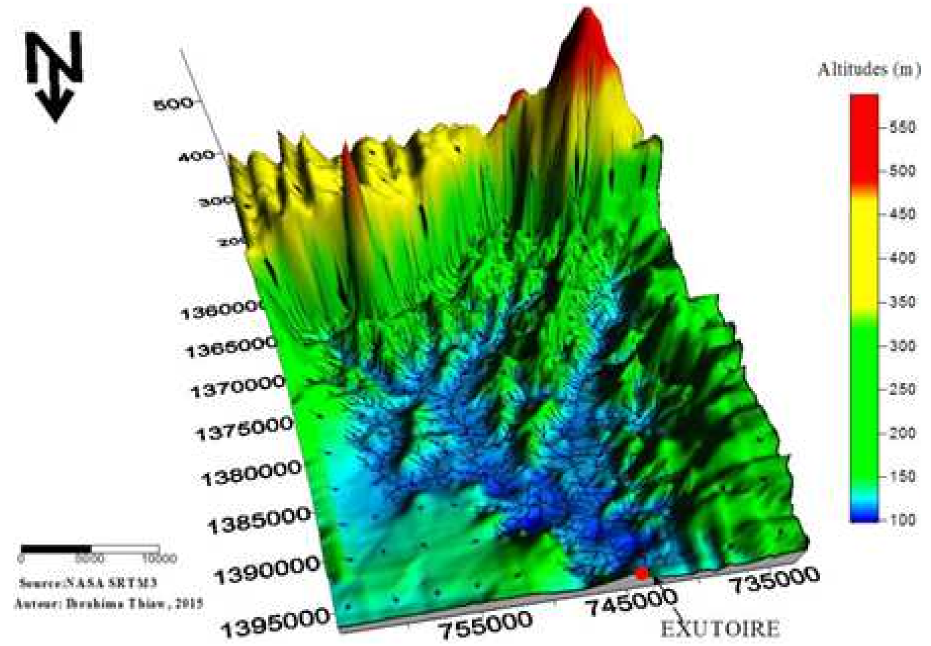

Figure 2. *The 3D Digital Terrain Model of the Diarha Basin.*

3. Materials and Methods

3.1. Materials

In this study several software programs have been used for the processing of climate and cartographic data, and the application of Geographic Information Systems (GIS) in the generation of thematic maps. These are mainly Arcgis, Erdas Imagine, Surfer, Khronostat, Hydraccess and HyfranPlus.

3.2. Methodology

3.2.1. Data

Three types of data are needed to carry out this work:

- Climatic data: these are climatic parameters such as temperatures and precipitation collected from the National Agency of Civil Aviation and Meteorology of Senegal (ANACIM);
- Map data: NASA SRTM data for the generation of the Digital Terrain Model (DTM), satellite data (Meteosat)
- And hydrological data collected at the level of the Water Resources Management and Planning Department (DGPRE). The measured flows of the basin extend over a period of 26 years (1972-2004)

3.2.2. Method Used for the Homogenization of Data

Precipitation for the missing periods of the basin stations is estimated using the RN (Normal Ratio) method or method. In the RN process, rainfall *P*, at station *A* is estimated from the normal of the monthly or annual precipitation of the station in question and those of the riparian stations for the period of missing data at the station in question according to The following equation [9]:

$$\mathrm{Px} = \frac{Nx}{n}\left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} + \cdots + \frac{Pn}{Nn}\right)$$

where *Px*: represents the missing rains at station *x* to be filled; *Nx* the annual rainfall mean at station *x; P1, P2, P3* and *Pn*, and *N1, N2, N3* and *Nn* corresponding to the rainfall values of stations *1, 2, 3*... *n* respectively and *n* representing the number of stations for which rainfall data are available.

The aptitude of the method is determined by the proximity of the estimates and the actual values in a given time series. Several descriptive error statistics can be used as a criterion for estimating the narrowness of real and calculated values such as: mean, standard deviation, and coefficients of variations and correlations. All stations with incomplete or short rains of annual and monthly rainfall have been supplemented or extended using this method (normal ratio) to cover the period 1921-2014.

3.2.3. Methodology of the Study of Climatic Variability

In order to assess the evolution of rainfall over the years, the rainfall index method was applied. The latter is known as the Nicholson Index and / or the Standardized Precipitation Index (SPI). This method has the advantage of highlighting the surplus and deficit periods. Thus, for each of the selected rainfall stations, an interannual rain index was determined. It is defined as a reduced centered variable expressed by the following equation [10]:

$$I_i = \frac{Xi - X}{s}$$

with: *Xi* the value of annual rainfall in year i; X interannual mean rainfall over the reference period, and S: standard deviation of interannual rainfall over the reference period.

The standardized precipitation indices (SPI) are classified into 6 main ranges of values, each of which represents the effect of the climatic phenomenon.

These ranges of values and their interpretation are obtained from the following equation:

$$A_i = \left(\frac{ni}{N}\right) * 100$$

with *Ai*: the percentage of years concerned by class *i*,

ni: the number of years in class *i*, and *N*: the total number of years in the study period.

3.2.4. Methodological Approach to Fracture Detection

The acceptance of hydrologists, as regards the annual totals of precipitation, is that from the stochastic point of view, these can be considered as a stationary process. The latter assumes that the basic properties of the process do not change with the temporality. Moreover, many recent studies point to an opposite situation [11, 12, 13]. It is assumed that in the context of climate change both the mathematical expectation and the variance of this random process at the interannual scale would no longer be independent from time to time. This is the reason why a statistical study on annual rainfall is undertaken, using the rank correlation test [14], the Buishand statistic and the Wood Ellipse [15], the Pettitt test [16, 17], the Bayesian method of Lee And Heghinian [18], and the normality test used in numerous studies to analyze the stationarity of the hydro-climatic series [10, 19]. These tests are also recommended by the World Meteorological Organization for the detection of changes within the time series [20]. They are programmed into the Khronostat software (developed within the ORSTOM Tropical Great Tidal Basin Program).

The choice of the methods chosen rests on the robustness of their basis and on the conclusions of a Monte Carlo simulation study. They are used to detect a change in the mean of the variable being processed in the time series. With the exception of Pettit's approach, they assume a non-change in the variance of the series studied [19].

3.2.5. Methodological Approach to the Spatial Study of Precipitation

The spatialization of the annual average rainfall was carried out over two different periods: 30-year slippery rainfall averages one succeeding each other every 10 years [21], and decadal 10-year mean rainfall (1921 to 2010). Normal 1951-1980 and the decade 1951-1960 (which is closer to the 10-year average) were used as a reference for the analysis of the spatial variability of annual precipitation. The method used is that of the polygons of Thiessen. This method is opted because, on the one hand, the simplicity of its implementation: the Thiessen coefficients being calculated once for the entire watershed, for a given number of stations; And on the other hand, because of the frequency of its use and the precision of the results [22, 23].

This method of Thiessen is "an arithmetic method in which each rain gauge is assigned a weight proportional to a presumed zone of influence, such that a point in that zone is closer in horizontal distance to the corresponding rain gauge than to any other rain gauge" [24]. Moreover, it is particularly suitable when the rainfall network is not homogeneous spatially, taking into account only the spatial distribution in plan of the stations.

The annual precipitated water table in the Diarha watershed was calculated by assigning the sum of the precipitation (Pi) of each station multiplied by their weighting factor (Area, Ai), divided by the total area of the basin slope:

$$\overline{P_{moy}} = \frac{\sum Ai * Pi}{A}$$

with *Pmoy*: Mean precipitation on basin *Pi*: precipitation of station i; Ai the area of the polygon associated with the station *i* and A the total area of the watershed = ΣAi.

The monthly precipitated water slide of a year X is obtained by the sum of the water slides of each month of the year *X* of the 10 stations of the basin

4. Results

4.1. Breakdown and Trend Detection Tests

To demonstrate the stationary or non-stationary nature of the rainfall series, statistical tests were used with the trend and rupture analysis on average. The trend term refers to the change in the properties of a random process that occurs gradually on the scale of the sampling period, whereas a break corresponds to a change that occurs suddenly, with the properties remaining stable the year of rupture [25].

The results of the analysis of the time series by the normality test conclude that the data of the series of studied stations follow a normal distribution (with logarithmic transformation for Kedougou).

The results of the detection of breaks (Table 1) show that the annual precipitation series are not stationary, as numerous studies have shown [26, 27, 28]. They show breaks on 4 different dates between 1965 (Kédougou) and 1979 (Fongolimbi). Most of the climatic ruptures were detected in 1967 (for 6 of the 10 stations in the Diarha basin). These observations corroborate the results of ICCARE program [10], which situate most of the disruptions between the end of the 1960s and the beginning of the 1970s in West and Central Africa

The Kendall rank correlation test, used to analyze trends in the series, shows a downward trend in annual precipitation from the selected stations at the 99% confidence level.

The annual rainfall averages of the sub-series of each station, calculated before and after the rupture, show a decrease of 46.1 mm (Fongolimbi) to 295 mm (Pita) after rupture. This fall corresponds to estimated deficits between 3.8% in Fongolimbi and 17.2% in Pita, an average of 10.5%. Thus, from the date of rupture in 1967, to the present day the average annual rainfall of the Diarha basin has decreased by about 10.5%.

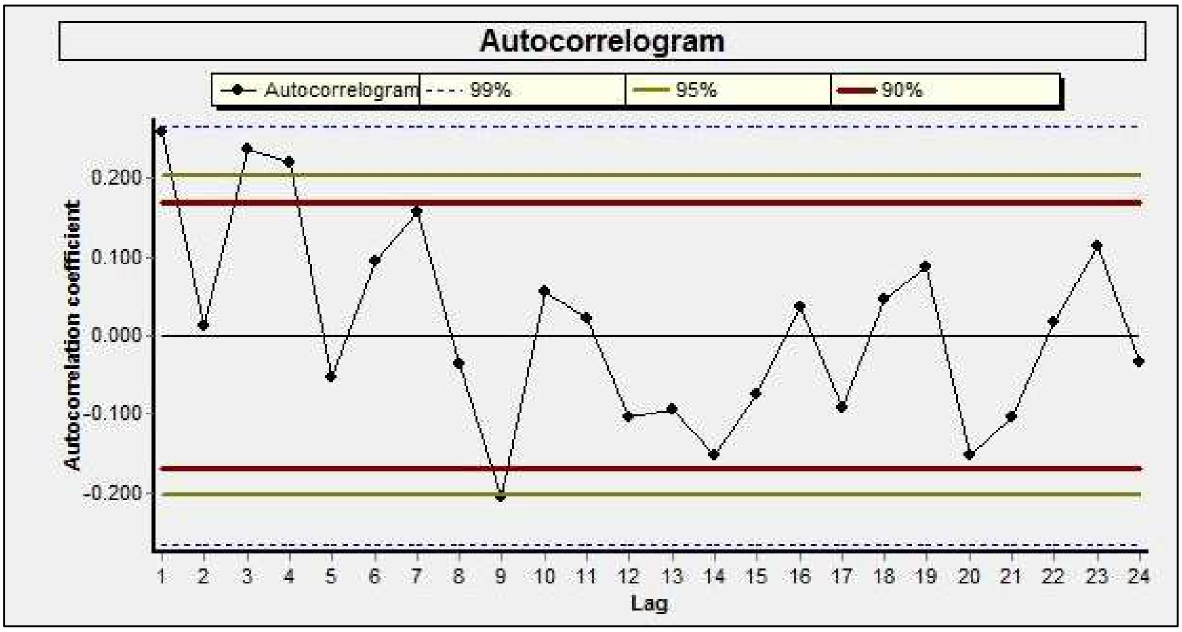

Figure 3. *Proof of the present of rupture by the Autocorrelograms of Labe.*

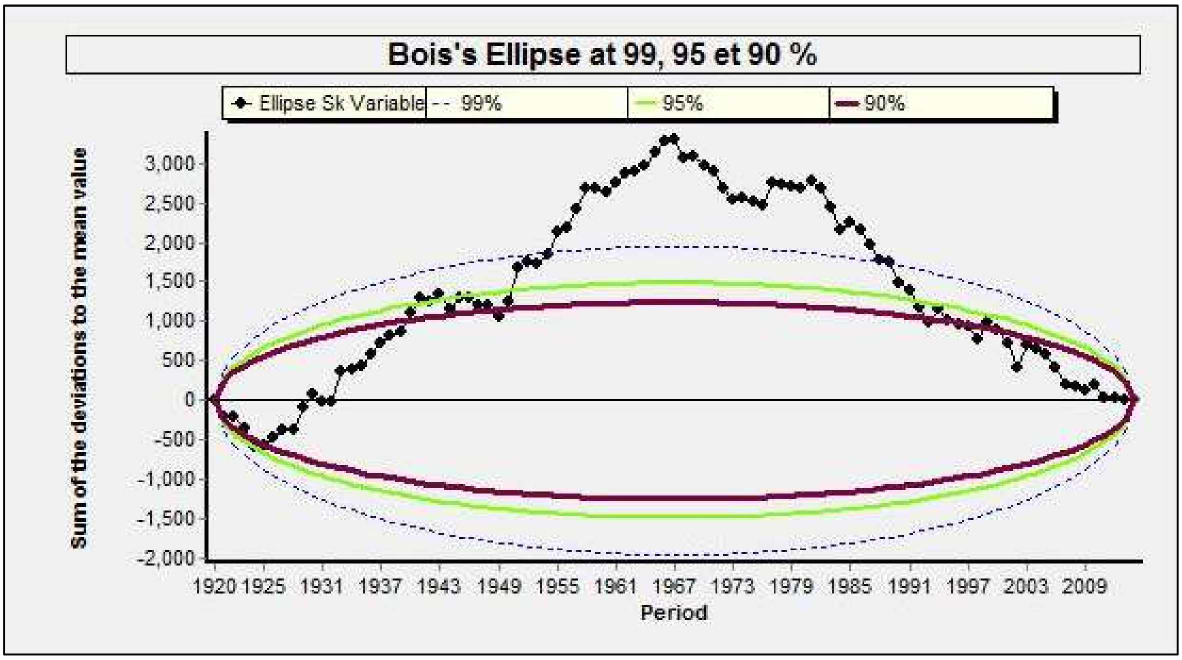

Figure 4. *Demonstration of the presence of rupture by the Bois's Ellipse at station of Dakately.*

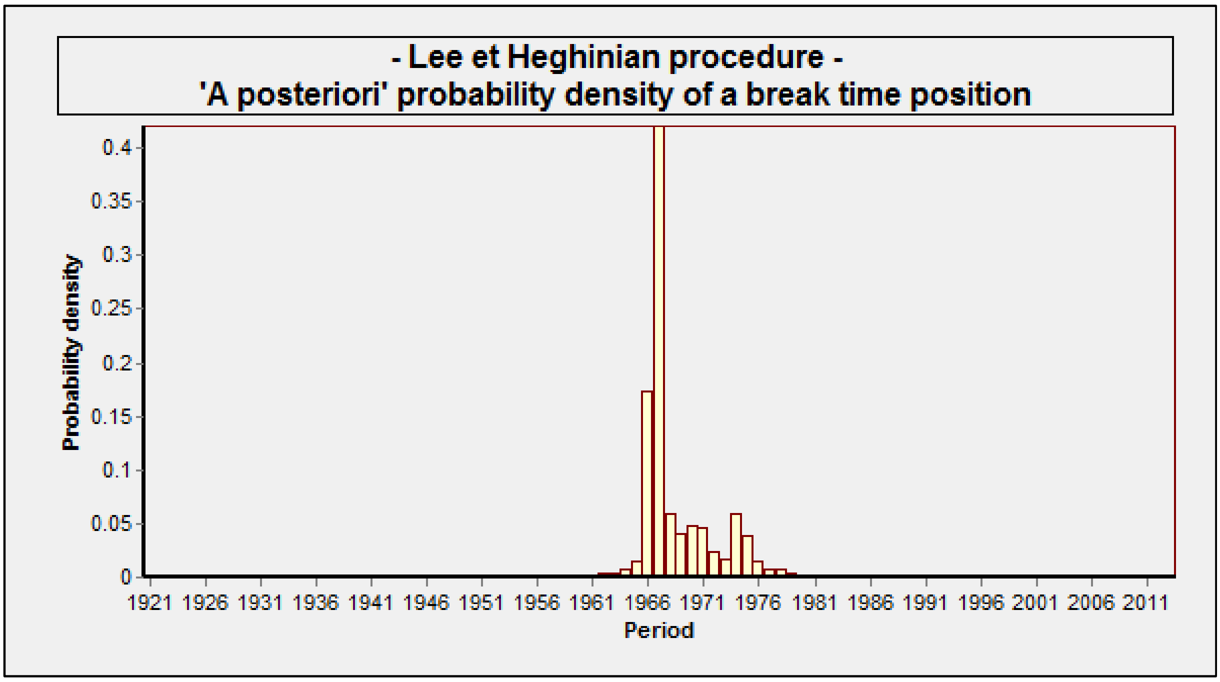

Figure 5. *Demonstration of breaking presence by the Lee and Heghinian test at station of Saraya.*

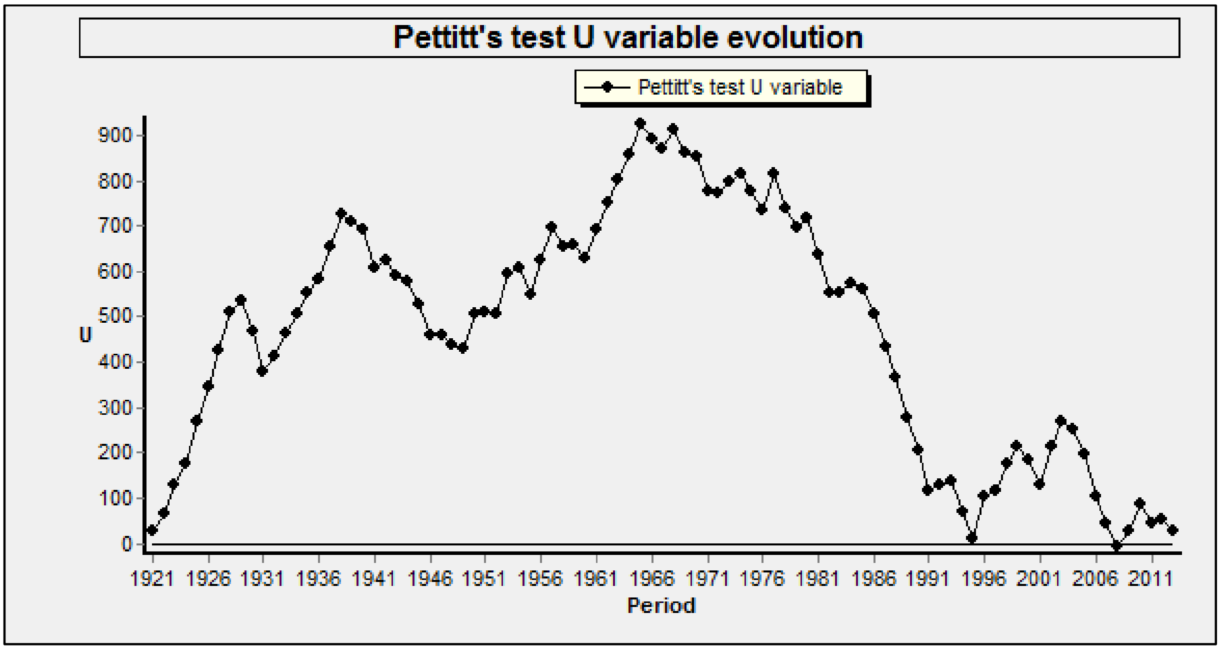

Figure 6. *Demonstration of the presence of rupture by the Pettit's test at the station of Kédougou.*

Table 1. *Results of statistical tests applied to annual rainfall chronicles.*

Stations	Random Character	Break Tests		Mean Before Break	Mean After Break	Difference (mm)	Deficit %
		Pettitt	Lee and Heghinian				
Dakately	Rejected at 99%	1967	1967	1239,5	1097,8	141,7	11,4
Kédougou	Rejected at 99%	1965	1965	1305,7	1169,4	136,2	10,4
Salémata	Rejected at 95%	1967	1967	1215,7	1074,2	141,4	11,6
Bandafassi	Rejected at 99%	1967	1967	1177,6	1041,7	136	11,5
Tougué	Rejected at 99%	1976	1976	1514,5	1317,1	197,3	13,1
Pita	Rejected at 99%	1967	1967	1711,5	1416,6	295	17,2
Labé	Rejected at 95%	1969	-----	1643,2	1496,6	146,6	8,9
Fongolimbi	Rejected at 95%	1979	1979	1207,4	1161,3	46,1	3,8
Saraya	Rejected at 99%	1967	1967	1151,1	1077,8	73,3	6,4
Laminia	Rejected at 99%	1967	1967	1236,6	1153	83,6	6,8

4.2. Study of Climatic Variability

The rainfall index is used to further analyze the interannual variation in precipitation in the two rainfall regimes of the basin because, in addition to its efficiency in the detection of surpluses and rainfall deficits, this index makes it possible to measure "The extent of drought (or humidity) for each of the years in the time series" [29].

The interpretation of rainfall data from the Nicholson indices or standardized annual rainfall indices shows that, depending on the station and the observation period, drought accounts for more than 50% (55% at Labe, 54.26% at Pita and Dakately, 51.07% in Tougué, and 50.5% in Kedougou). The Diarha watershed has had years of extreme drought, for example, in 1977 in Salemata, 1983 in Tougué, and 1990; 1992 and 2007 in Kedougou. All of these rainfall deficits are on the second phase of the annual rainfall totals (1968-2014), marked by chronic deficiencies over the total rainfall regimes of the Diarha basin. However, it recorded a few years of extreme humidity, mostly during the period from 1921 to 1967: it was the years 1929 and 1954 in Kedougou, and 1933 and 1951 in Tougue and Dakately.

Table 2. *Proportions (%) of dry and wet years per station.*

Classe SPI	SPI<-2	-2<SPI<-1	-1<SPI<0	0<SPI<1	1<SPI<2	SPI>2
Interpretation	**Extreme Drought**	**High Drought**	**Moderate Drought**	**Moderate Humidity**	**High Humidity**	**Extreme Humidity**
Kédougou (1921-2014)	3,2%	9%	38,3%	33,2%	12%	4,3%
Fongolimbi (1921-2014)	1,06%	18,09%	29,78%	35,11%	13,83%	2,13%
Saraya (1921-2014)	1,06%	14,89%	36,17%	32,98%	11,71%	3,19%
Salémata (1921-2014)	2,13%	14,9%	32,98%	38,29%	8,51%	3,19%
Laminia (1921-2014)	1,06%	20,22%	30,85%	29,78%	15,96%	2,13%
Bandafassi (1921-2014)	2,13%	10,64%	37,23%	37,23%	10,64%	2,13%
Dakately (1921-2014)	0	18,09%	36,17%	30,85%	12,76%	2,13%
Tougué (1921-2014)	1,06%	15,97%	34,04%	34,04%	12,77%	2,12%
Labe (1921-2014)	2,13%	3,19%	50%	29,78%	14,9%	0
Pita (1921-2014)	0	15,96%	38,3%	34,04%	7,45%	4,25%

4.3. Calculation of Precipitated Water Slides

In the Diarha catchment, there is a variation of the annual precipitated water slides, the series of which is subdivided into two periods characterized by the deficit and the surplus according to the interannual mean of 1164 mm.

The first period from 1921 to 1967 has an annual average of 1234.7 mm, while the second period (1968-2014) stands out with an annual average of 1094.1 mm**.**

The variation of this average water received in the catchment is more noticeable by observing the annual rainfall deviations from the average in the Diarha catchment (Figure 7). Until 1967, the precipitated water slides on the basin were clearly in surplus. The succession of deficit years is shorter, over two to three years, as is the case in 1947-1949 and 1921-1924.

After 1967, there was a collapse of precipitated water slides with a succession of dry years longer, over two to three decades in which there were some surplus years such as 1974, 1977, 1994, 1999 and 2003.

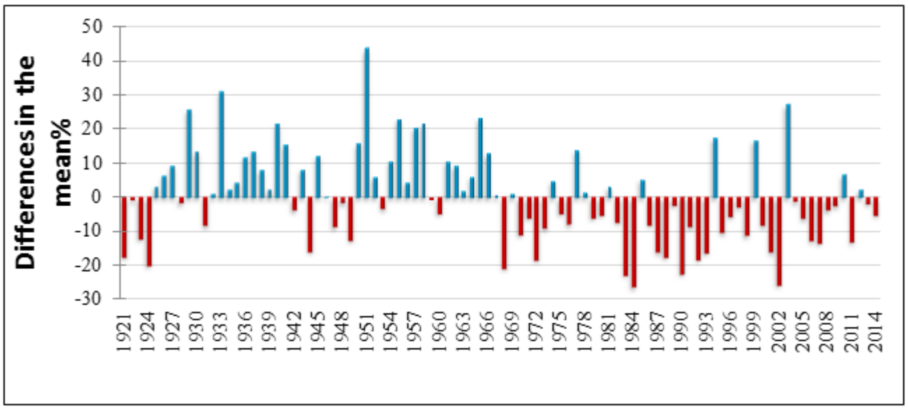

Figure 7. *Average deviations of the precipitated annual water slides on the Diarha.*

Seasonal Variability of Monthly Rain

The data used in this study are obtained from the monthly rainfall file homogenized by the interpolation technique of the normal ratio of the 10 stations of the basin. From the observations of these different stations, the monthly precipitated water plate on the Diarha basin is calculated. Its knowledge is of paramount importance because it provides an overview of how annual rainfall is distributed on a seasonal or monthly basis in the watershed. The method applied is that of the polygons of Thiessen, integrated in the software Hydraccess.

Average monthly rainfall is unevenly distributed. In fact, the analysis of the figure 8 shows that the precipitated water slides are mainly concentrated between the months of April and November. They oscillate from May to August, decrease gradually from August to October, then suddenly from October to December. The rainy season varies between 7 and 8 months in the Diarha watershed.

The precipitated monthly mean precipitated water slides calculated before and after breaking (Figure 9) show that for almost all months' precipitation decreased between the two periods. The decrease is particularly evident outside the dry season.

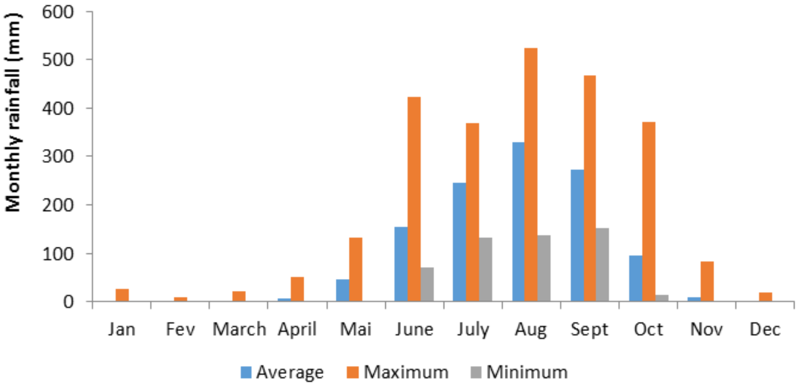

Figure 8. *Average monthly change in mean rainfall (1921-2014).*

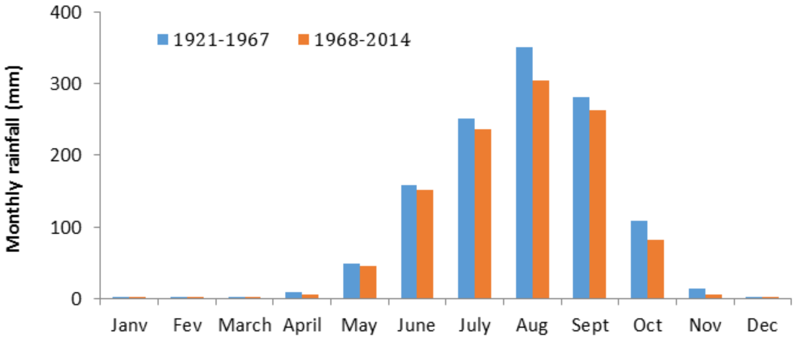

Figure 9. *Precipitated monthly average pre- and post-rupture water slides.*

4.4. Study of the Spatial Variability of Rainfall

Analysis of maps of variations of inter-normal isohyets shows that the normals (1931-1960 and 1941-1970) were the most humid in the Diarha basin. The first normal had isohyets that ranged between 1224 mm to the north and 1314 mm to the south, and the second to the isohyets which varied between 1206 mm in the north and 1296 mm in the south. During this period, the decrease in annual rainfall is marked by the migration of isohyets to the north.

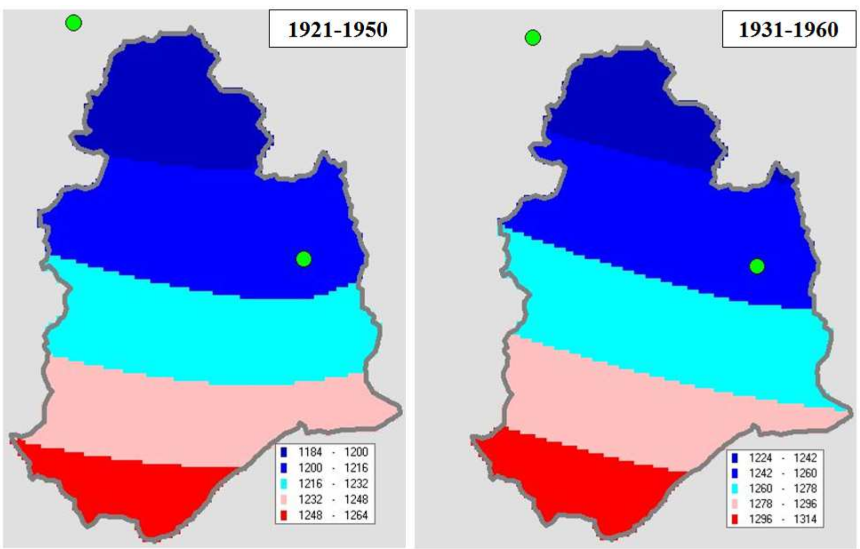

Figure 10a. *Spatial variation of inter-normal isohyets.*

Moreover, the normals (1951-1980, 1961-1990, and 1971-2000) are marked by a migration of the isohyets in the opposite direction that is to say towards the South. The Normal 1971-2000 was the most deficient of all these climatic normals. It is marked by a descent of the isohyets towards the south, with averages varying between 1044 mm to the north and 1152 mm to the south (figure 10).

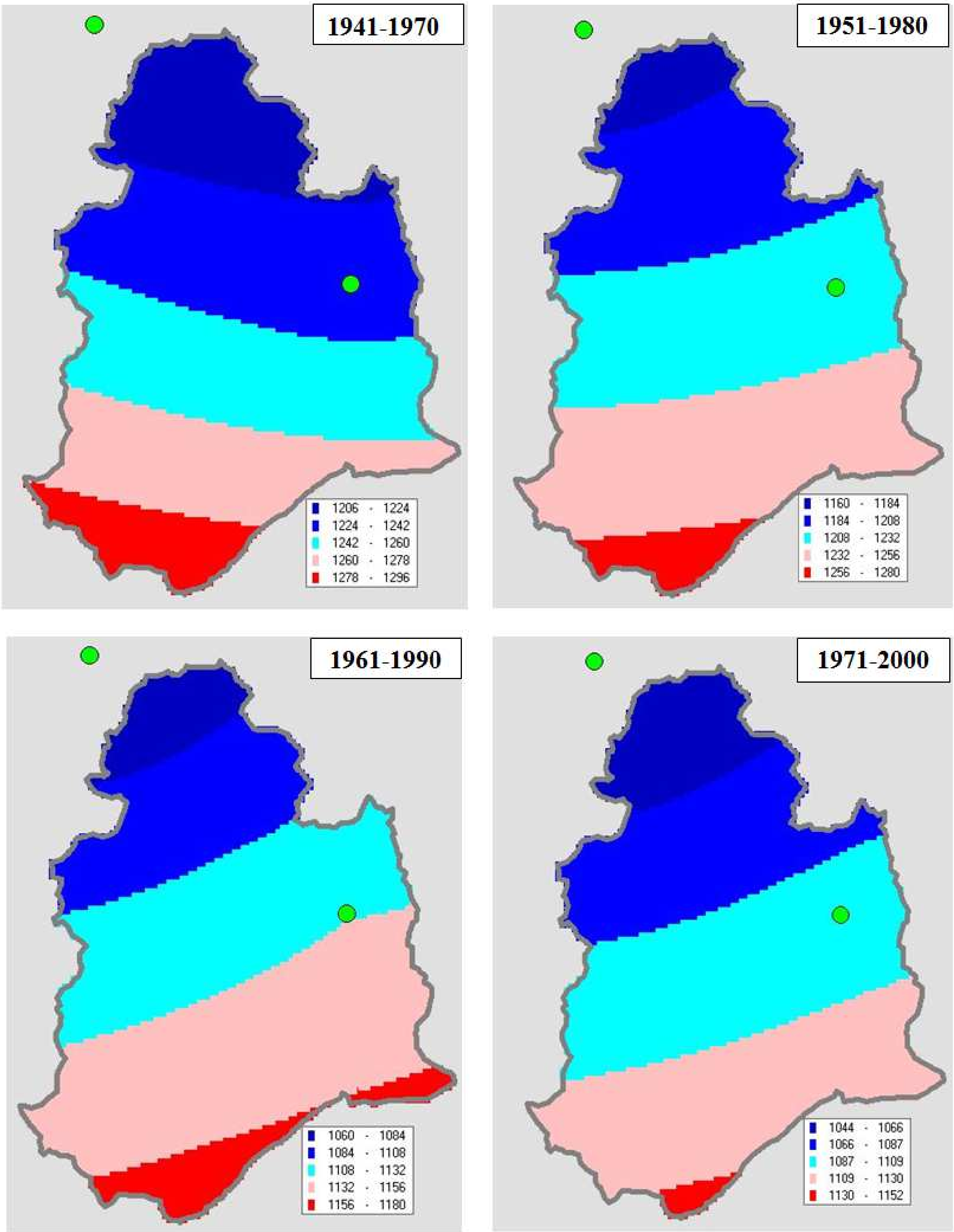

Figure 10b. *Spatial variation of inter-normal isohyets.*

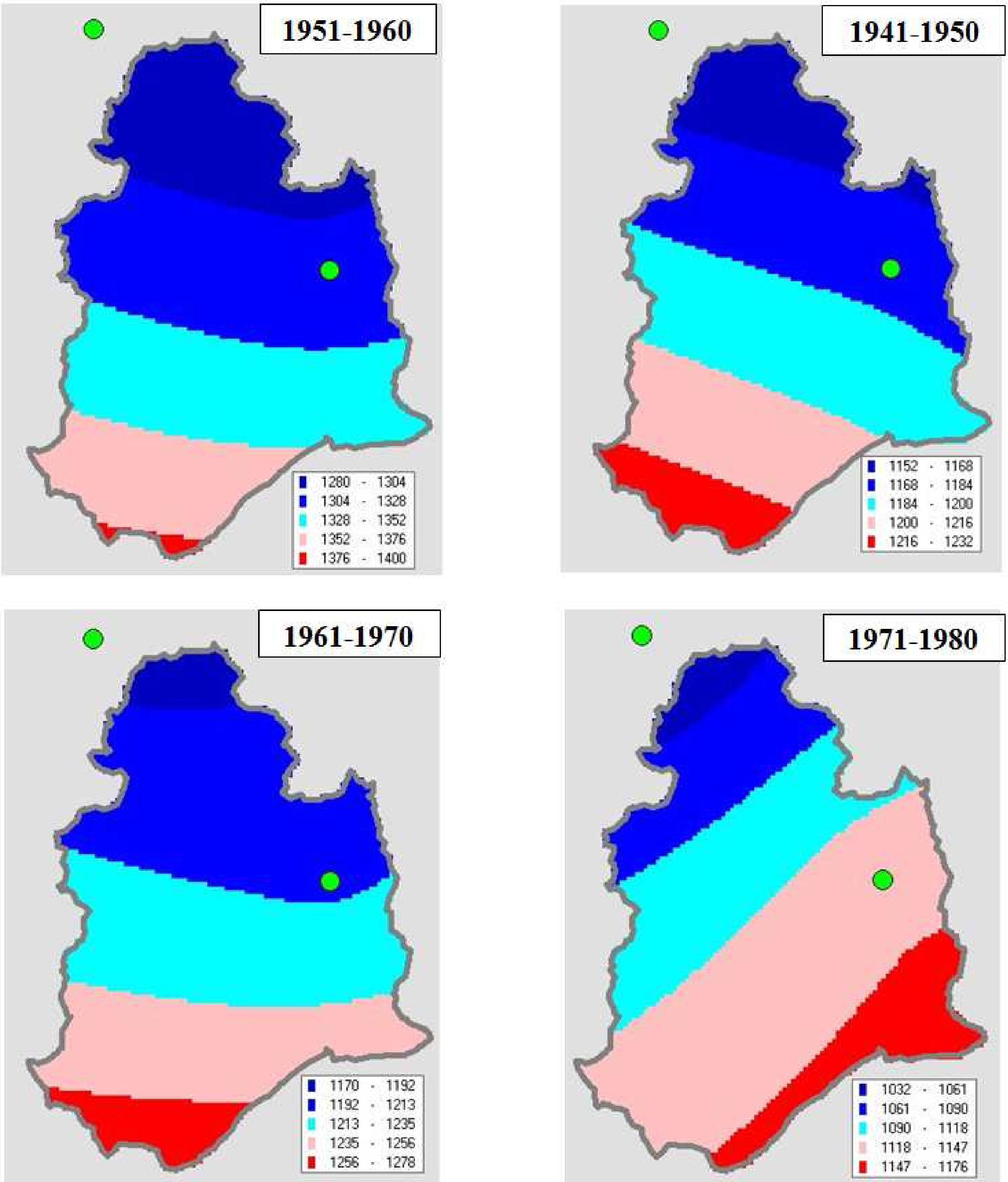

Figure 11a. *Spatial variation of inter-decadal isohyets.*

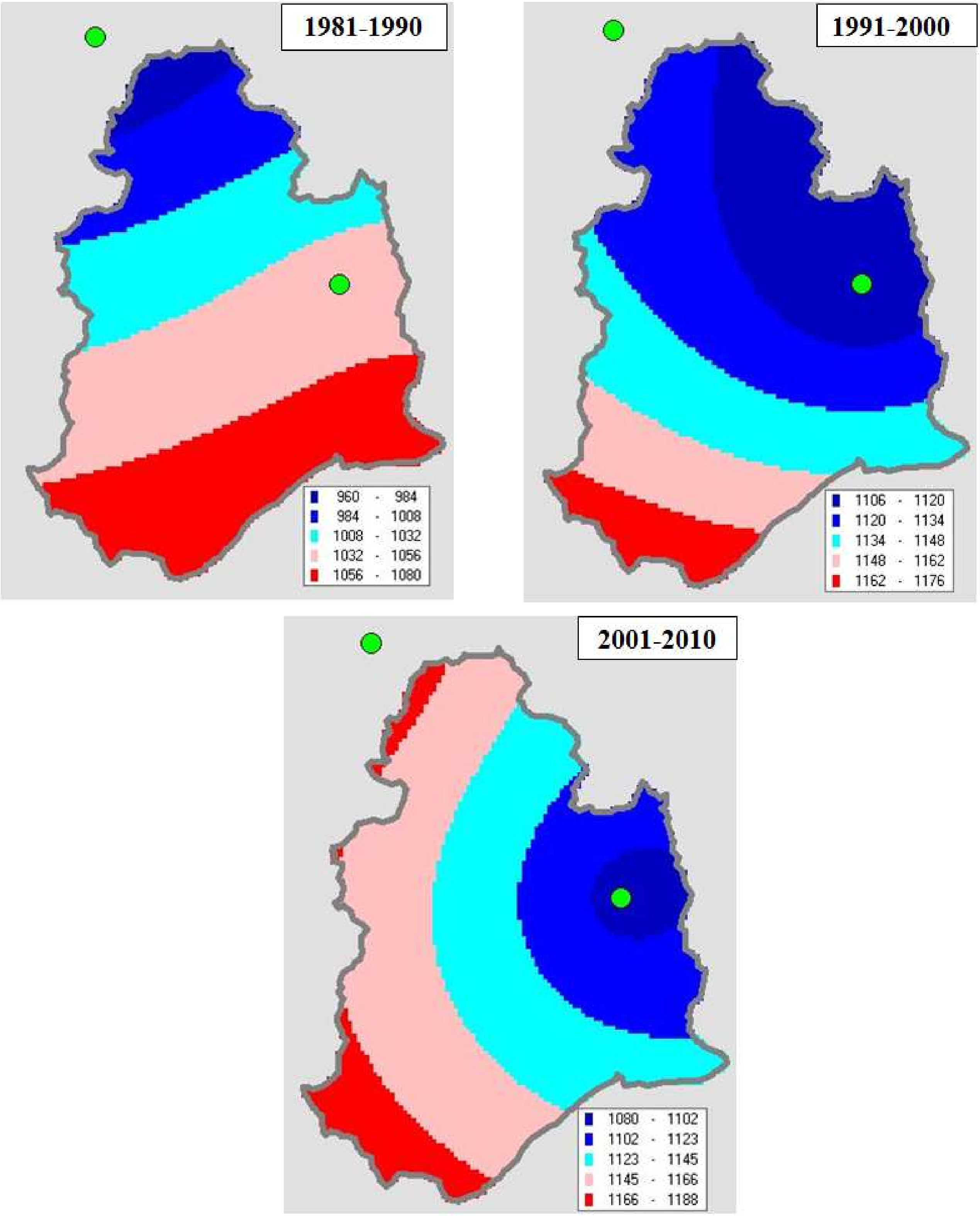

Figure 11b. *Spatial variation of inter-decadal isohyets.*

The observation of maps of the inter-decadal isohyets (Figure 11) gives a more detailed view of the decline in rainfall. The latter has gradually decreased in time and space with a migration of isohyets towards the south. The decade 1951-1960 is the wettest with annual averages included, from North to South between 1280 mm and 1400 mm. From this decade, the isohyets descended from the decades (1971-1980 and 1981-1990) towards the south. These dry periods can be interpreted as manifestations of the severe drought that struck West Africa from the late 1960s and mid-1990s [2, 3, 10].

The last two decades of 1991-2000 and 2001-2010 are marked by a tendency to recover annual rainfall, but they are still low. This confirms the work of [30] at the level of the central and western Sahel rainfall regime.

Overall, the evolution of decennial and inter-normal averages of annual rainfall heights shows a decrease in both the minimum and maximum. This decline resulted in a shift of the isohyets towards the south in the "less" rainy zone in the north (in the South Sudanian domain); while those in "strong" precipitation zones are located in the south (in the Guinean climate domain) and in the central-east of the Diarha basin.

4.5. Flow Variability

4.5.1. Interannual Variability of Flows

The analysis of the variability of the annual flows is done with the hydraulic coefficient. The Diarha watershed at the road bridge has over 12 years of surplus years (46%) and 14 years of deficit, which is 54% (Figure 12).

The years 1975 (193.7%), 1999 (187.4%) and 2003 (183.3%) recorded the highest hydraulicity values during the period 1972-2004. The year 1984 recorded the lowest hydraulicity value (30.4%). This year is also the most deficit (-26.3%) from the point of view of rainfall throughout the Diarha basin. It conferred on the basin of isohyets which varies between 774 mm in the North and 961 mm in the South, that is to say an average of 867, 5 mm.

The average interannual flows follow the same evolutions modeled on those of the precipitated water slides which result from a random phenomenon that is the climate. The maximum module (DMAX) 13.8 m^3/s of this time series is observed in 1975 and the minimum module (DMIN) 2.2m^3/s is in 1984. The average annual flows are largely dependent on the quantities Monthly rainfall data received and the resulting monthly flows in a tropical environment. But they do not faithfully represent the latter. They summarize some information that can only be detected through the analysis of the seasonal (or monthly) variability of flows.

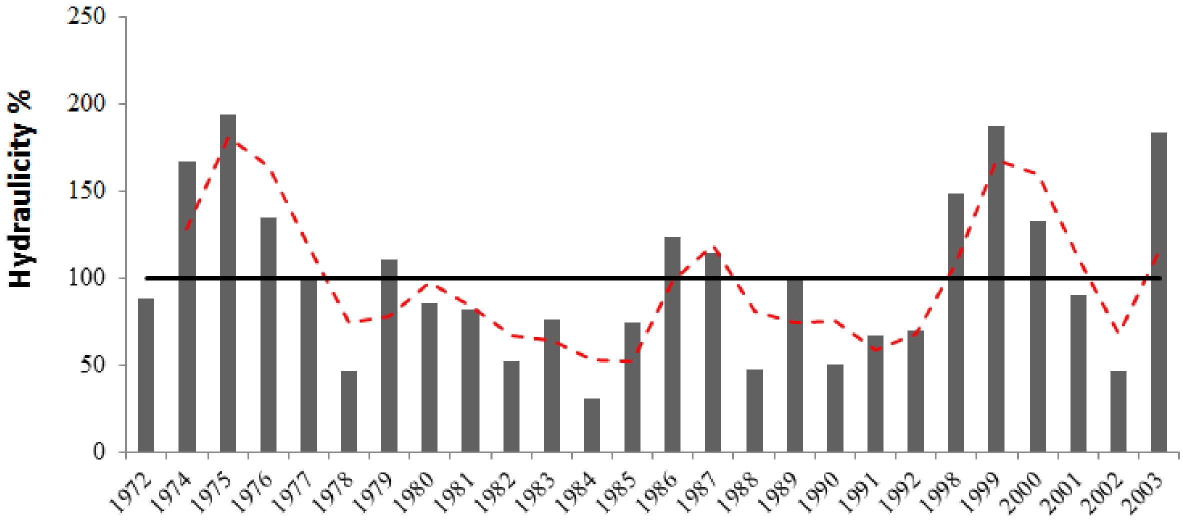

Figure 12. *Interannual Variation of Hydraulicity in the Basin.*

4.5.2. Seasonal Variability of Flows

The study of the seasonal variability of flows makes it possible to determine the average hydrological regime of the watercourse. The hydrological year begins on 1 May and ends on 30 April in the case of Senegal [31]. This is illustrated in the table below, which shows the average monthly flows and the monthly flow coefficients (CMDs) of the series (1972-2004). The CMD is the ratio of the average flow in a given month to the average annual flow (7.1m^3/s). According to the classification of Pardé (1968), a CMD greater than or equal to 1 corresponds to a period of high waters and a CMD less than 1 is assimilated to a period of low waters.

Table 3. *Seasonal variation in flows.*

Diarha Watershed	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
Monthly Debits	0,1	0,6	8,2	22,8	34,1	14,2	2,2	0,7	0,2	0,1	0,02	0,02
S. Deviation	0,4	0,8	11,2	14,7	22,4	9,2	1,3	0,5	0,2	0,0	0,1	0,3
C. V	4,7	1,3	1,4	0,6	0,7	0,6	0,6	0,7	1,1	1,5	4,6	4,9
CMD	0,01	0,08	1,18	3,28	4,90	2,03	0,32	0,09	0,02	0,01	0,01	0,01

Based on the data in the above table, the high-water period is concentrated over four months (July, August, September and October) with a single peak in September (34.09 m^3/s). This maximum is offset from the maximum rainfall in August. This lag can be explained by the delay in the delivery of rainfall.

The month of September appears as the month of the normal annual flood in the Diarha watershed for 38.5% of the cases. Early flooding occurred in July (11.5% of cases), semi-early in August (34.6% of cases), and late in October

(15.4% of cases).

The low-water period extends over 8 months (November to June) with only one minima in April (0.01 m^3/s). The hydrological regime of the Diarha is of tropical type of transition (4 months of high waters), influenced by the Guinean domain, but also seasonal because the flow depends only on the rainfall and the aquifers that sometimes support the flows.

4.5.3. The Study of the Flow Balance

Pond flows are highly dependent on precipitated water slides and potential evapotranspiration. The hydrological balance is obtained according to the formula:

$$P(mm) = L\ (mm) + E\ (mm) + R1 - R0$$

P (mm): the precipitation height received by the watershed; L (mm): average annual water leakage, that is, the volume of water discharged from the watershed surface; E (mm): water slide returned to the atmosphere by actual evapotranspiration;

R1 and R0: represent respectively the water slides placed in reserves, stored in the ground or the underground aquifers and restored by these same aquifers during a given period. However, over a long period R1-R0 tends to equilibrate (R1-R0).

All the parameters of the water balance shown in Table 4 were determined using the Hydraccess and HyfranPlus softwares, with the mean daily flows and mean rainfall of the basin as input variable. These results show that the annual runoff of the basin is quite high (25% of the average rain received). However, they are heavily dependent on precipitated pools of water per year and potential evapotranspiration. The latter occupies 75% of the average rain received. To this must be added the influence of pedology and geology (the river flowing over the Proterozoic and Paleozoic formations of the Birrimian basement), but also of the high topography of the basin, in this case the relief and its slope system. All these factors combine in space and time to allow for high values of basin runoff.

Because the flood point (Qmax) occurs only once in the year, floods only experience interannual variation. The interannual irregularity of the floods is analyzed by parameters such as the coefficient of variation (CV = standard deviation / mean).

They reflect a strong dispersion of the modules around their average (Table 4). This interannual irregularity is also expressed by the coefficient of immoderation of PARDE (R) which is the ratio between the maximum and the minimum of the series.

Table 4. *Annual flood statistics for the Diarha from 1972 to 2004.*

	Flood Base Time (Days)	Flood Rise Time (Days)	Qmax (m^3/s)	Elapsed Volume (m^3)	Tumbled Volume (m^3)	Flow rate (m^3/s)	Stream flow (m^3/s)	Elapsed Water Blade (mm)	Turbidity Water Blade(mm)
Average	220	57	91,1	212.623.320	191.719.400	11,4	10,2	280,0	252,5
S. Deviation	49,2	27,2	36,5	105703540,3	102.665.888	5,1	5,0	139,2	135,2
C. Variation	0,2	0,5	0,4	0,5	0,5	0,4	0,5	0,5	0,5
Maximum	327	107	169,2	432.520.000	402.830.000	21,5	19,2	569,6	530,5
Minimum	112	8	41,2	64.228.000	36.514.000	3,8	2,1	84,6	48,1
Coef. R (Pardé)	2,9	13,4	4,1	6,7	11,0	5,7	9,0	6,7	11,0
Quartile 25%	201	57	61	133.040.000	133.040.000	6	6	175	175
Median	233	69	94	184.930.000	162.720.000	12	10	244	214
Quartile 75%	267	94	111	274.910.000	259.010.000	16	14	362	341

Knowledge of the extent of their variations is essential in order to implement economically and safely water resource development projects. However, any project in the field of water (retention pond, irrigation works, hydroelectric installations, etc.) requires knowledge of a critical flood hydrograph, or at least the knowledge of the peak value of this hydrograph. The structure considered must be sized to allow passage of this critical flood without damage to its elements, with a certain frequency expressed in time of return. This flooding associated with a return time is the project flow of the structure [32].

4.5.4. Predetermination of Floods

The annual flows of the Diarha basin are applied statistical distribution models allowing the estimation of the flows of rare or exceptional frequencies.

The objective of this study is to find a frequency model that best suits the experimental data of the different hydrological parameters of the watershed. To this end, various laws integrated into the Hydraccess software [33] have been tested.

The law adopted is the one with the most significant adjustment in the sense of the BRUNET-MORET test (1977). This test calculates the area between the curves of the experimental and theoretical distributions, favoring the law which best adjusts to the extreme values.

Goodrich's law adjusts to the data of past flows and annual flows of water, Pearson's law 3 to flows and Gumbel's law at the time of rising flood. However, other parameters such as Qmax, trickled water slides, and base times follow a log-normal or Gibrat-Gauss distribution.

Table 5 shows the adjustment results of these different hydrological parameters of the Diarha watershed. The results range from the dry centennial to the wet centennial, and reveal a great temporal variability of the annual flows on the Diarha.

The Diarha is a powerful, well-fed river whose flow becomes practically continuous in the rainy season. In humid centennial recurrence, a maximum instantaneous flow (Qmax) of at least 219.1m^3/s is expected at the Diarha hydrometric station every 100 years. On the other hand, in dry 100-year recurrence, the latter is only 36.75m^3/s for the same return period. A Qmax of about 96.73m^3/s has a one in two chance of breeding.

Table 5. *Result of adjustment of the hydrological parameters of the Diarha watershed.*

Descriptors	Deficit Periods					Median	Excess Periods					K3
Length of Return (year)	**100**	**50**	**20**	**10**	**5**	**2**	**5**	**10**	**20**	**50**	**100**	
Frequencies	0,01	0,02	0,05	0,1	0,2	0,5	0,8	0,9	0,95	0,98	0,99	
Qmax (m^3/s)	36,75	41,77	50,14	58,51	69,98	96,73	131,35	153,33	173,86	199,87	219,11	2,6
Flowrate m^3/s	2,99	3,46	4,37	5,36	6,79	10,06	13,78	15,82	17,54	19,49	20,80	2,9
Stream flow m^3/s	1,41	2,10	3,25	4,39	5,93	9,39	13,57	16,06	18,29	20,97	22,86	3,6
Elapsed W. Blade (mm)	80,8	86,6	100,5	119,6	153,0	252,9	400,2	494,8	581,3	687,1	762,3	4,1
Turbidity W. Blade (mm)	35,1	45,6	68,1	95,7	139,7	254,3	402,9	491,2	568,5	659,8	722,9	5,1
Flood Base Time (Days)	106,7	121,2	143,0	162,4	185,9	230,8	275,7	299,1	318,5	340,3	354,9	1,8
Flood Rise Time (Day)	18,26	23,38	31,57	39,40	49,62	71,70	97,58	112,82	126,41	142,85	154,53	2,8
Elapsed Volume m^3	89.303.653,9					186.711.224	386.801.635,6					4,3
Tumbled Volume m^3	72.773.189					193.271.807	373.296.886,4					5,1

Decennial floods are also high. They are estimated at 153.3 m^3 s^{-1}, in wet decennial recurrence, and 58.51m^{3}s^{-1} in dry recurrence. The irregularity coefficient (K3), which is the ratio between the wet decennial and the dry decennial, is equal to 2.62. This means that the flow measurement station of the Diarha could record in wet recurrence, double the maximum flood rate received in the dry decennial.

The decadal flood is that caused by decadal rainfall (rainfall equaled or exceeded once every 10 years on average), and it is a fictitious flood whose main characteristics should be Observed once every 10 years on average [34]. However, it is quite possible to observe a flood discharge greater than the estimated decennial flow, one year after the construction, or 30 years after reaching it again. This is why it is more appropriate to say that true decennial floods (Q10 in wet and dry recurrences) are within the limits of:

Q10 ± 2 S (Q10) with a reliability of 95%

Q10 ± 3 S (Q10) with a reliability of 99.7%

With S (Q10) representing the standard deviation of Q10 which, in practice, is expressed in % of Q10 and is obtained by the following formula [35]:

$$S\,(Q_{10}) = \frac{CV}{\sqrt{n}} * 100$$

where CV is the estimated coefficient of variation of the annual flow and n is the average daily flow observation time.

Thus, in a wet recurrence, a decadal flood between 130.96 and 175.64 m^{3}s^{-1}, has about 99.7% chance of breeding every 10 years. On the other hand, in dry recurrence, a decadal flood between 36.17 and 80.85 m^3 s^{-1} has a 99.7% chance of recurrence over the same period of return.

The reading of table above also shows that the annual volumetric intakes of the basin are high. They are estimated at 89,303,653.9 m^3, in dry decennial recurrence, compared with 386,801,635.6 m^3, in decennial wet recurrence. An elapsed volume of at least 186,711,224.2 m^3 has a one-in-two chance of breeding, indicating that in the long term, the basin is capable of providing large volumes of water, despite their temporal variability.

5. Discussion

The study of annual precipitation by breaking tests, the Nicholson indices, and the Thiessen method (for spatial analysis) clearly showed the decrease in annual totals during the current dry period, but did not describe the phenomenon by looking for which parameters have varied significantly.

In order to better understand the causes of rainfall variability, the influence of drought on daily rainfall was determined by studying daily rainfall fractions. The available daily rainfall data only concern the Labe station for the period 1921-2004.

The analysis of the results obtained shows that the daily rainfall fractions evolve independently. F1 and F2 vary slightly, with coefficients of variation between 0.13 and 0.213 (Table 6). On the other hand, F3 varies much more with higher coefficients of variation. Thus, a tendency to decrease the cumulative rainfall of more than 40 mm (which are considered to be the heavy rains) seems to be evident from the year of rupture (1969) at Labe (Figure 13). Moreover, this fraction F3, on its own, explains on average 60% of the variation of the annual rainfall. These results are in agreement with those presented for Burkina-Faso by [26] and for the Upper Senegal River basin [36]. They also confirm the remarks of [37], which states that the precipitation deficit in the drier after rupture is mainly due to the decrease in the number of events occurring during the rainy season.

Table 6. *Some characteristic parameters of daily rainfall fractions.*

Station Labe	Period 1923-2004			Period Before Break			Period After Break		
Daily Rainfall Fraction	**F1**	**F2**	**F3**	**F1**	**F2**	**F3**	**F1**	**F2**	**F3**
	0-20	**20-40**	**>40**	**0-20**	**20-40**	**>40**	**0-20**	**20-40**	**>40**
Average	678	579	365	691	592	442	661	555	268
S. Deviation	110	123	182	126	125	188	85.7	118	115
C. Variation	0.162	0.212	0.499	0.182	0.211	0.425	0.130	0.213	0.429

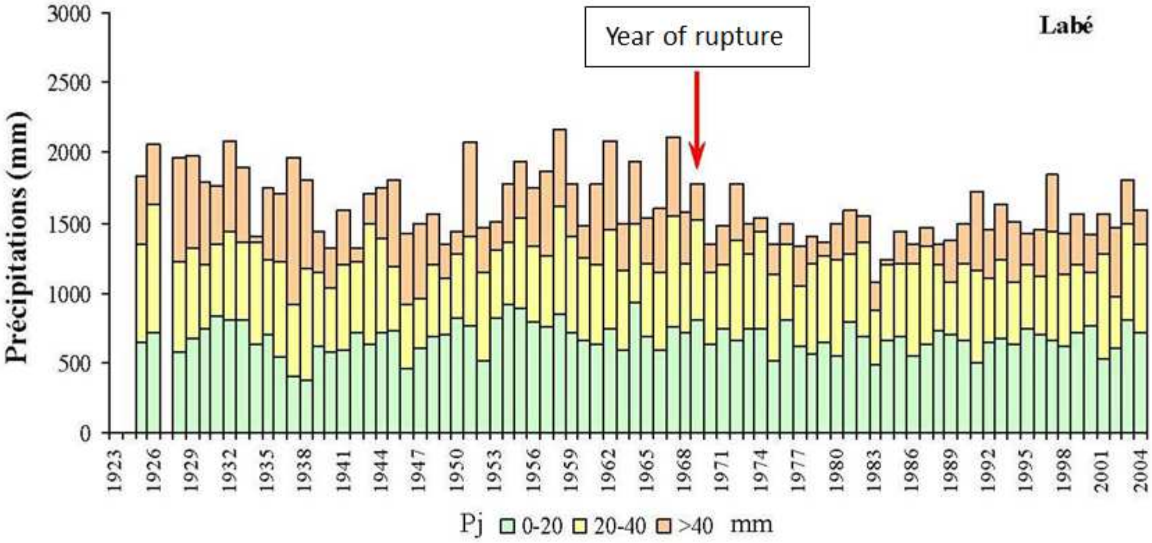

Figure 13. *Annual values of different rainfall fractions (daily rainfall <20 mm, 20-40 mm and> 40 mm).*

The Diarha watershed has a tropical transitional regime (4 months of high water). But this regime evolves towards a pure tropical regime (3 months of high waters) in normal rainfall year and towards a tropical Sahelian regime in a very deficient year (1983/84). The current rainfall deficit has therefore strongly influenced the Diarha hydrological regime as has been observed in several tropical watersheds. It is the example of the Gambia River at Kedougou station [38] and the Niger at Koulikoro [39], two stations belonging to the tropical transitional domain. In addition, knowledge of the Diarha's hydrological regime and the extent of its variations is a good indicator of the seasonal availability of surface water, whose control and management are a priority for the hydro-agricultural development of this hydrological system.

6. Conclusion

The study of rainfall variability showed that the Diarha basin is marked by triple variability: interannual variability, seasonal variability and spatial variability of precipitation. It was undertaken to better understand the phenomenon of drought and its repercussions on the water supply of the basin and on agriculture. Two climatic cycles were highlighted. The first one runs from 1921 to 1967 and is generally humid and the second from 1968 to 2014, largely deficit compared to the first.

Until 1967, precipitated water slides were clearly in surplus. The succession of deficit years is shorter, two to three years, as is the case in 1947-1949 and 1921-1924.

After 1967, there was a collapse of precipitated water slides with a succession of dry years longer, over two to three decades, as was the case in 1968-1993. This decline in rainfall is attributable to the drought of the 1970s, which began in 1968 in all the climatic regimes of the basin, and whose amplitude studied through the SPI is greater than that of the wet period (more than 50%). Moreover, this phenomenon is not specific to the Diarha watershed. This is a problem that affects all of Africa in recent times. At the domestic level, this phenomenon can be linked to deforestation. On the other hand, on the external plane, it would be linked to a slight change in the atmospheric circulation. Nevertheless, the drought is less severe than that in West Africa and especially in the Sahelian zone since 1970. Dry years have not been severe throughout the catchment: from the period of rupture (1967), to date, the mean annual rainfall of the basin has decreased on average by 10.5%.

Rainfall is the basic element of hydrology. His knowledge is essential to that of flows.

The study of water supplies from the Diarha basin to the road bridge has made it possible to estimate the state of the resource in the long term in order to make its use more adequate, but also to plan water control measures such as hydro-agricultural works. It revealed that the Diarha is full of important water resources that contribute to the strengthening of the water potential of South-East Senegal and that for a suitable development could constitute a raw material source of development.

References

[1] DE MARSILY G. (2006): Inland waters. Institute of France, Academy of Science, 356 pages.

[2] PATUREL JE, SERVAT E., DELATTRE MO, AND LUBE-NIEL H., (1998): Analysis of long-term rainfall series in non-Sahelian western and central Africa in a context of climatic variability, Hydrological Sciences Hydrological Sciences, 43 (6) December 1998, pp. 937-946.

[3] DACOSTA H., KONATÉ Y. K., AND MALOU R. (2002): The spatial and temporal variability of precipitation in Senegal over a century; FRIEND 2002; Regional Hydrology: Briging the Gap Between Research and Practice (proceedings of the fourth international FRIEND conference held at Cape Town, South Africa, March (2002), IAHS Publ., 274, pp. 449-506.

[4] SOW A. A (2006): Hydrology of South-East Senegal and its Guineo-Malian borders: the basins of Gambia and Falémé. Ph.D. thesis in Humanities, Department of Geography, UCAD, 1232 pages, 457 figures, 661 tables and annexes.

[5] KONATÉ L., (1998): Lowlands in the river system of the Gambia River: (Cartography, Hydrological regimes, agricultural valorization and typology). PhD of Geography, UCAD-ORSTOM, 207 pages.

[6] OLIVRY J. C., (1983): Evaluation of hydrological and meteorological data available on the Gambia River basin (collection, quality, interpretation); Preliminary Report, ORSTOM-OMVG, 94 pages.

[7] ALBERGEL J., LAMAGAT J. P., BOUCHEZ J. M., AND DECROIX L. (1990): Hydrological Monograph of the River Gambia; ORSTOM-OMVG, 256 pages.

[8] MICHEL P. (1973): The basins of the rivers Senegal and the Gambia: Geomorphological study; Volume 1, Memory ORSTOM-Paris, 810 pages.

[9] MOHANTY P. K., PANIGRAHI D. AND ACHARYA M. (2014) MissRF: A Visual Basic Application in MS Excel to find out Missing Rainfall Data and Related Analysis. Intelligent Information Management, 6,844. Http://dx.doi.org/10.4236/iim.2014.64006.

[10] SERVAT E., PATUREL J. E, LUBE-NIEL H., KOUAME B., TRAVAGLIO M. and MARIEU B., (1999): Various aspects of the variability of rainfall in non-Sahelian western and central Africa; Journal of Water Science / Journal of Water Science, Vol. 12, No. 2, pp. 363-387. http://id.scholar.org/iderudit/705356ar.

[11] HUBERT, P. & CARBONNEL, J. P. (1987**).** Statistical approach to the aridification of West africa. 1. Hydrol. 95,165-183.

[12] SNIDJERS T. A. B. (1986): Interstation correlations and non stationarity of Burkina Faso rainfall. Journal of climate and applied meteorology. Flight. 25 pp. 534-531.

[13] MUSY A AND MEYLAN P. (1987): Modeling of a non-stationary process. Application to rainfall in semi-arid zones. I. A. H. S. Publ. No. 168, 1987 - pp 287-299.

[14] WMO 2000: Twenty years of progress and achievement of the WMO tropical cyclone programme (1980-1999).

[15] BUISHAND T. A., (1982): Some methods for testing the homogeneity of rainfall records, Journal of Hydrology, Vol. 58, pp. 11-27.

[16] PETTIT A. N., (1979). A non-parametric approach to the change-point problem, Applied Statistics, vol. 28, No. 2, p. 126-135.

[17] DEMARREE, G. (1990**).** An indication of climatic change as seen from the rainfall data of a Mauritanian station. Theoret. Appl. Climatol. 42, 139-147.

[18] LEE A. F. S. & HEGHINIAN S. A., (1977): A shift of the mean level in a sequence of independent normal random variables - a Bayesian approach. Technometrics, Vol. 19, No. 4, p. 503-506.

[19] LUBES-NIEL, H., MASSON, M., PATUREL, J. E. & SERVAT, E. (1997) Climatic variability and statistics. Study by simulation of the power and the robustness of some tests used to check the homogeneity of chronicles. URI: id.erudit.org/iderudit/705313ar;

[20] WMO - WMO (2000): Detecting trends and other changes in hydrological data. In: Kundzewiccz ZW; Robson A. eds. World Climate Program Data and Monitoring. WCDMP-45, WMO / TD No. 1013, Geneva.

[21] KOUASSI E. A, YEI MARIE S. O. YAO B. K. AMANI M. K., NAGNIN. S. JEAN B. Hydro geochemical and microbiological characterization of water resources of a Technical Landfill Center (CET) in Côte d'Ivoire: case of the CET of Kossihouen in the District of Abidjan (Côte d'Ivoire). http://indexmedicus.afro.who.int

[22] METTIN J. L (1994): Calculation of the precipitated water slide on the Ubangui watershed in Mongoumba (1972-1992). Master's thesis, University of Bangui, 135 p.

[23] SARR J., (2007): The basins of the Tararé watershed (Central West Groundnut Basin): Mapping - Potential - spatial strategies for sustainable development; Ph.D. thesis in Geography, UCAD, 331 pages, 38 maps, 18 photos, 39 figures and 29 paintings.

[24] ROCHE M. (1963): Surface Hydrology, ORSTOM and Gauthier- VILLARS, Editeur-Paris 1963, 439 p.

[25] PERREAULT L., BERNIER L, BOBÉE B, PARENT E**.** Bayesian change-point analysis in hydrometeorological time series. Part 1. The normal model revisited. Journal of Hydrology, 2000.

[26] ALBERGEL J. (1986) - Assessment of rainfall in Sudanese-Sahelian Africa example from Burkina Faso. In: CIEH Symposium on the Revision of Hydrological Standards following the Impacts of Drought (Ouagadougou), 19 p.

[27] KHODJA H., LUBES-NIEL H., SABATIER R., MASSON J.-M., SERVAT E., and PATUREL J.-E., (1998): Spatio-temporal analysis of pluviometric data in West Africa, Kuwait, Research of a rupture on average, An interesting alternative: the permutation tests, Revue de statistique applied, volume 46, n° 1, pp 95-110.

[28] KHOUALDIA W., DJEDDAR Y. AND HAMMAR Y. (2014): Characterization of climatic variability: case of the Medjerda watershed (Algerian Northeast). Rev. Sci. Technol., Synthesis 29: 6-23 (2014).

[29] DAO A., et al. (2010): Climatic Variability and Hydrological Response of the Kolondièba Transboundary Watershed in southern Mali, European Journal of Scientific Research; ISSN 1450-216X Vol, 43 No. 4, pp. 435-444. http://www.eurojournals.com/ejsr.htm

[30] LEBEL T. and ALI A. (2009) - Recent trends in the central and western Sahel rainfall regime (1990-2007). *Journal of Hydrology*, vol. 375, p. 52-64.

[31] DACOSTA H., (1989): Precipitation and flow on the Casamance basin, PhD thesis, UCAD, Department of Geography, 277 pages.

[32] MUSY A. (1998): Applied Hydrology, HGA Bucharest, 368 p

[33] VAUCHEL P. (2000): Hydraccess, software for importing, storing and processing IRD database.

[34] BERTON S. (1988**)**: Flood control in lowlands, small and micro-dams in West Africa; GREF, CF, ACCT 475 pages.

[35] KLEMES V. (1975): Application of hydrology to the management of water resources: (At the planning and design level); WMO - No. 356 - Geneva - Switzerland, 121 pages.

[36] BODIAN A, DACOSTA H AND DEZETTER A. (2011). Spatio-temporal characterization of the rainfall regime of the Upper Senegal River basin in a context of climatic variability. Physio-Géo, Volume 5 | -1, 107-124.

[37] LE BARBÉ L., LEBEL T. and TAPSOBA D. (2002) . Rainfall variability in West Africa during the years 1950-90. *Journal of Climate*, vol. 15, p. 187-202.

[38] LO H. M (1984) - The Gambia basin upstream of Gouloumbou. Contribution to hydrology and river dynamics in the African tropical humid environment. Doct. of the 3rd cycle Univ. Nancy II, 396 p. 55 fig. 10 cards + 38 pictures.

[39] BALLO A. - 1984 - Modalities of river flow in the tropical African wetland. The example of the basins of Niger and Bani - Doct. Of the 3rd cycle - Univ. Nancy II - 176 p. - 33 fig.