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Rainfall Disturbances in the Context of Climate Change in the Diéma Circle, Mali

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Abstract*— The evolution of rainfall is of great concern to Sahelian countries and particularly Mali. Thus, this research focuses on the analysis of rainfall disturbances in the context of climate change in the Diéma circle. To do this, a mixed methodological approach was used involving the collection of quantitative and qualitative data. The results show that rainfall has changed significantly over the last 60 years in the Diéma circle. This evolution is illustrated by a large fluctuation in annual rainfall amounts with a break detected in the rainfall series and by a poor spatio-temporal distribution of rainfall marked by the recurrence of dry sequences. It is also marked by a trend towards shortening the duration of rainy seasons from 1960 to 2019. These rainfall disturbances in the Diéma circle are a sign of climate change.*

Keywords*— Rainfall, Disturbances, Climate change, Circle of Diéma, Mali*

I. INTRODUCTION

The scientific community today agrees that climate change is already a reality. The intensity and duration of the warming observed in the 20th century are unprecedented for a thousand years. An increase is recorded in maximum temperatures, number of hot days and heat index in almost all countries during the 2nd half of the 20th century. All the evidence allows us to conclude that the warming observed over the last fifty years is mainly attributable to human activities [1]. Furthermore, the outlook is worrying according to [2] which concludes that the projections made on the basis of all the emissions scenarios considered indicate an increase in surface temperature during the 21st century. It is very likely that the frequency and duration of heat waves will increase, and that extreme precipitation will become more intense and more frequent in many regions. The oceans will continue to warm and acidify and average sea levels will rise.

Africa, although less responsible for climate change, is one of the regions of the world that suffers the worst devastating effects caused by this scourge [1]. Indeed, for [3], Africa has already felt the impact of climate change and we can expect even more marked effects. So, in general, areas that have had precipitation, such as the equatorial and subpolar rainfall belts, will have even more, while dry areas, such as subtropical arid zones, will have even less. As a result, the arid and semi-arid zones of the North, West, East and partially South of Africa have become drier while equatorial Africa and the rest of the South are becoming wetter. Indeed, according to [4], the increase in average temperature between 1980/1999 and 2080/2099 could reach between 3 and 4°C across the entire continent, 1.5 times more than at the global level. This increase will be less strong in coastal and equatorial areas (+3°C) and higher in the western part of the Sahara up to +4°C.

Mali is experiencing an upheaval in the climate in general and particularly in rainfall. Thus, according to [5] the analysis of monthly rainfall also reveals a random distribution of rainfall at the start and end of the rainy season. The average annual rainfall varies greatly from north to south. Monthly and annual rainfall totals reflect a decrease in precipitation in latitude. [6] concludes that since the appearance of periods of drought in the 1970s, we have observed the establishment of a more arid climate over the entire territory, a trend towards an overall reduction in useful rainfall of 20% and a movement of the isohyets of 200 km towards the South.

The climate of the Diéma circle is Sahelian with an isohyet of 600 mm. A climate characterized by two seasons: a rainy season of 3 to 4 months (June, July, August and September) and a dry season of 8 to 9 months. This dry season is punctuated by two periods: a cool period (November to March) and a hot period (April, May and June) [7]. For more than three decades, the rainfall in the area has not been what it was before. She is experiencing changes.

Thus, this work is interested in climate change and particularly in the evolution of rainfall. Therefore, the objective of this article is to analyze rainfall disturbances in the context of climate change in the Diéma circle.

II. METHOD AND MATERIALS

The methodology adopted for this article is composed of the presentation of the site and the methodological approach used.

2.1 Location of the site

The Diéma circle occupies the eastern part of the Kayes region in Mali. It is limited to the west by the circle of Bafoulabé, to the east by the circles of Kolokani and Nara (Koulikoro region), to the north by the circle of Nioro du Sahel and to the south by the circle of Kita. The geographic coordinates of Diéma are: Latitude (14º 34’ 59”) and longitude (9º 15’ 0”).

With an area of 12,440 km², the Diéma circle has 15 communes including 14 rural communes and one urban commune: Diéma, Madiga-Sacko, Dianguirdé, Dioumara-Koussata, Gomitradougou, Groumera, Béma, Fassou-Débé, Guédébiné, Diangounté- Camara, Lambidou, Lakamané, Diéoura and Sansankidé and the urban commune of Fatao.

The chief town of the circle (Diéma) is located 276 km from Kayes via Lakamané, 350 km from Bamako via Kolokani, 105 km from Nioro du Sahel and 200 km from Kita.

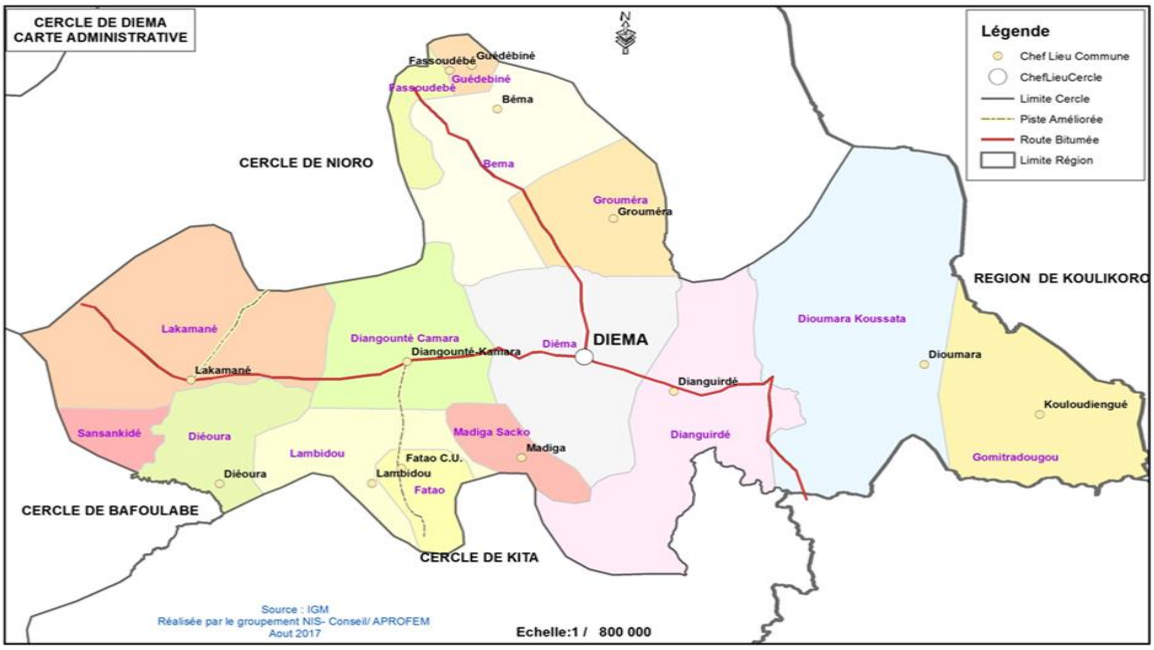


Figure 1: Map of the Diéma circle

2.2 Methodological approach

The methodological approach used is mixed. Beforehand, consultation of documents in several documentation centers and libraries was very useful, because it allowed the structuring of ideas for the development of this article.

2.2.1 Collection and processing of ethno-meteorological data

Data was collected following field surveys to find out farmers' perceptions of rainfall. For the collection of quantitative data, the questionnaire was used as an instrument. For this purpose, the quantitative sample was constituted at three levels (see table 1):

- *Municipality level :* With a representativeness rate of 33%, the sample is set at 5 municipalities out of the 15 that make up the Diéma circle. The geographical criterion is used for the selection of the 5 communes: (Béma in the North, Diéma, Gomitradougou and Lakamané in the center and the commune of Dianguirdé in the South).
- *Village level :* For the choice of survey villages, we opted for systematic random sampling. The 5 municipalities surveyed are made up of 78 villages which constitute our sampling base. Based on a representativeness rate of 32%, we obtained 25 survey villages. The selection of these villages by survey commune was carried out proportionally to the size of the communes surveyed, i.e. 32% of the villages in each commune were selected.

Thus, for the commune of Béma which has 24 villages, our sample corresponds to 8 villages. The selection was made from the list of villages classified in alphabetical order. To do this, we first calculated the sampling step K.

K=N/n

K= no survey; N= total number of villages; n= number of survey villages

K= 24/8= 3

TABLE 1: Municipalities, villages and Agricultural Production Units selected for the quantitative survey

Communes	villages	Agricultural Production Units
Béma	Badiané	25
	Diarra Madina	19
	Fadou	28
	Kakanou	08
	Kamidala	07
	Koungo	15
	N'tomikoro	10
	Torgomé	08
Dianguirdé	Beïdy	12
	Foulabougou	12
	Nacoumana	06
	Torodo	12
Diéma	Bougoudéré Mahomet	24
	Diéma	19
	Fangouné Bambara	95
	Kana	19
	Mambrouké	07
Gomitradougou	Bassibougou	8
	Missira	06
	Sébabougou	21
Lakamané	Dalibera	13
	Foutougou	09
	Kabakoro	05
	Kobokoto	14
	Lattakaf	18
Total	25	420

Given that K=3, the first village to be surveyed was drawn between the numbers 1 to 3. For this purpose, we wrote down the names of the first 3 villages in our sampling frame on pieces of paper which were put in a box. The box was then shaken vigorously, then the pieces of paper were poured out. A random choice fell on the third village on the list which is Badiané. To select the second survey village, we carried out the calculation 3+3=6, so the 6th village on the list is chosen, the village of

Diarra Madina. Then to draw the third village to investigate, we set the operation 6+3=9, so the 9th village on the list is taken, the village of Fadou. So, we took the 8 survey villages in the commune of Béma. The survey villages taken are: Badiané, Diarra Madina, Fadou, Kakanou, Kamidala, Koungo, N'tomikoro and Torgomé.

This procedure for selecting survey villages was used for the other survey communes.

- *Agricultural Production Units (APU) level*: with a sample of 420 APUs out of 1288 of the 25 survey villages, the representativeness rate is 32.6%. The UPA draw is carried out according to a sampling interval and a random starting point. The lists of UPA heads available from village chiefs were used as a sampling frame.

For the qualitative data, an interview guide was developed and interviews were carried out with municipal elected officials, technical service agents, district council agents, NGO agents, etc.

TABLE 2: Number of resource people interviewed per municipality and per village

Municipalities	Villages	Number of people interviewed					
		Men's focus group	**Women's focus group**	**Municipal elected officials**	**Technical services**	**NGO**	**circle board**
Béma	Badiané	06		01	02		
	Diarra Madina	09					
	Fadou						
	Kakanou	08					
	Kamidala						
	Koungo	06	11				
	N'tomikoro						
	Torgomé	07					
Dianguirdé	Beïdy			01			
	Foulabougou		06				
	Nacoumana	05					
	Torodo						
Diéma	Bougoudéré Mahomet			01	04	04	01
	Diéma						
	Fangouné Bambara	12	08				
	Kana						
	Mambrouké	06					
Gomitra-dougou	Bassibougou		13	01	01		
	Missira						
	Sébabougou	10					
Lakamané	Dalibera		06	01	01		
	Foutougou	04					
	Kabakoro						
	Kobokoto						
	Lattakaf.	06					
Total	25	79	44	05	08	04	01

Data processing consisted of the use of data collected in the field concerning rainfall disturbances. These data were processed with tools including SPSS and Excel which are software for statistical analysis and Microsoft Word for word processing.

2.2.2 Processing and analysis of meteorological data

The rainfall data used in this document are those of the Nioro station (the station closest to the Diéma circle). They were provided by the National Directorate of Meteorology of Mali. These are monthly and annual rainfall data from 1960 to 2019. The statistical processing mainly concerned the detection of breaks in the series and the determination of rainfall trends. For this purpose, several methods were used:

- For rupture detection, the SNHT (Standard Normal Homogeneity Test) test was applied to the rainfall series.
- Regarding the study of climate variability, the Rainfall Anomaly Index (IAP) was used. Calculating the IAP makes it possible to define dry years and wet years [8].

$$IAP = (Xj-X)/S$$

Or :

Xj: annual rainfall amount for year j;

X: average annual rainfall at station i during the duration of the study;

S: standard deviation of annual rainfall for the time series.

Thus, dry years are those whose IAP are $\leq$ -1 and wet years are those whose IAP are $\geq$ + 1.

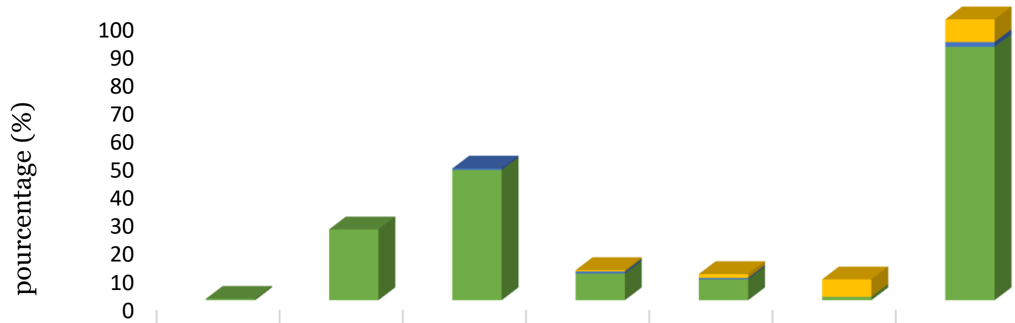
In addition to the Rainfall Anomaly Index, indices on total rainfall and the start and end dates of the rainy season are also used.

III. RESULTS

The rainfall has changed a lot in the Diéma circle. This evolution is manifested by multidimensional rainfall changes.

3.1 Trends in annual rainfall

According to farmers, rainfall is characterized by a general downward trend between 1960 and 2019. This decline is perceived by 379 out of 420 UPA heads surveyed, i.e. 90.2% (Figure 2).



	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	total
Augmentation				0.5	1.4	6.2	8.1
Constance			0.5	0.7	0.5		1.7
Diminution	0.5	25.2	46.4	9.5	7.4	1.2	90.2

Diminution Constance Augmentation

Figure 2: Farmers' perception of the evolution of annual rainfall between 1960 and 2019

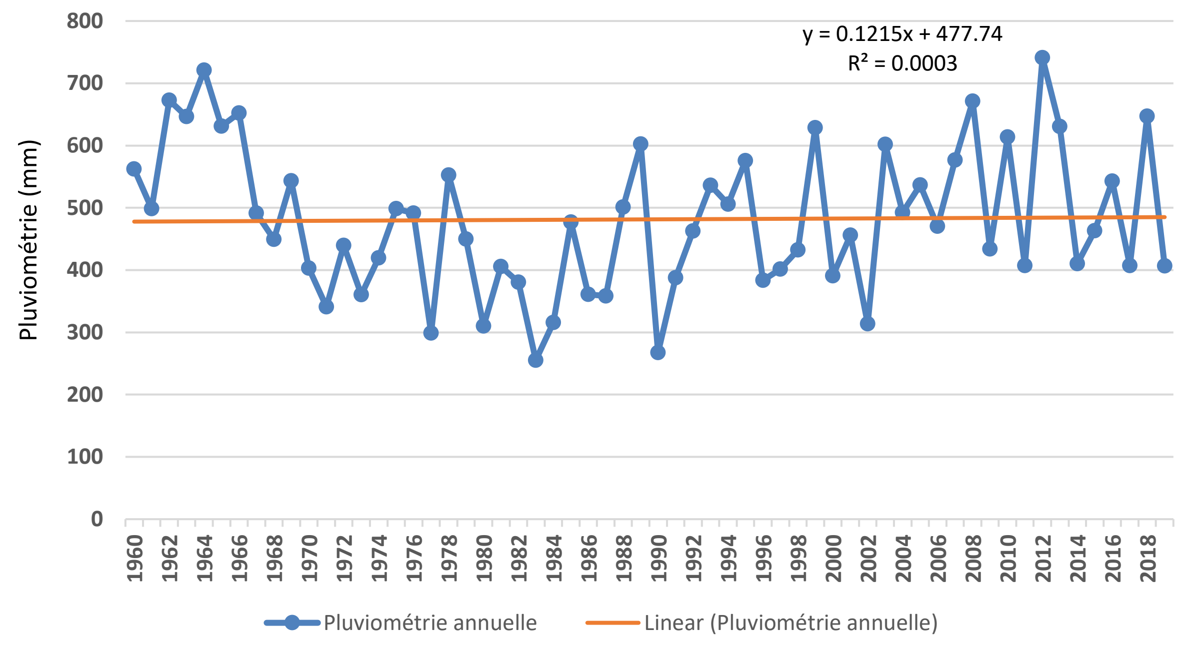


Figure 3: Evolution of annual rainfall from 1960 to 2019.

The interpretation of ethno-meteorological data indicates that the rainfall trend is regressive. Even if in detail, people explain that the last three decades seem to have been wetter than the 1970s and 1980s.

This perception of farmers and the conclusion of meteorological data partially converge on the evolution of annual rainfall. Indeed, meteorological data show a general slightly upward trend in annual rainfall totals over the 60-year series (1960-2019). The analysis of this series shows a great variability in annual rainfall over this period with an average of 481.4 mm. The average rainfall increased from 469.6 mm in the period 1960-1989 to 493.1 mm in the period 1990-2019, an increase of 5%. Or again, the average rainfall increased from 411.1 mm in the two-decade period 1970 - 1989 to 510.6 mm in the two-decade period 2000-2019, an increase of 24.2%. In the series, the highest annual rainfall occurs in 2012 with 740.8 mm compared to the lowest in 1983 with 255.3 mm.

Furthermore, in order to assess the evolution of rainfall from 1960 to 2019, the calculation of the Rainfall Anomaly Index (PIA) was carried out to define dry years and wet years. The magnitude of the annual rainfall anomalies is -1.95 to +2.23 mm. The rainfall indices were determined: i > 1 for years with excess rainfall and i < -1 for years with deficit rainfall. Thus, the five-year smoothed average shows, generally speaking, three periods in the precipitation trend: a wet period from 1960 to 1969; a deficit or dry period from 1970 to 2005, marked by the droughts of 1973 and 1983 in the Diéma circle; and a wet period from 2006 to 2019.

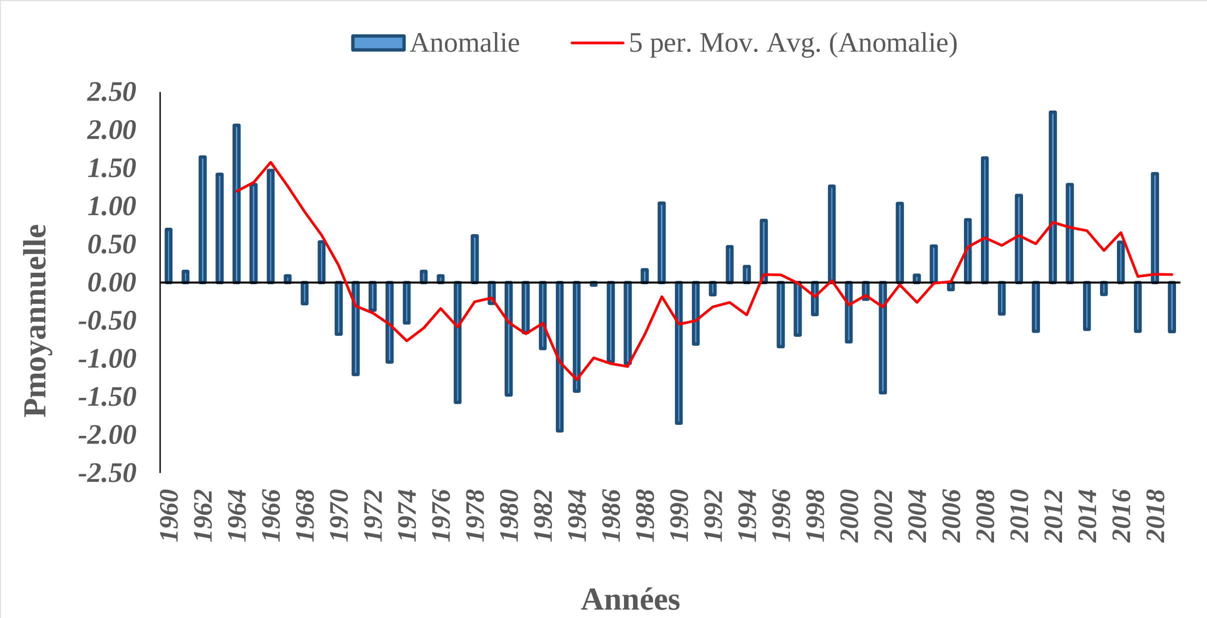


Figure 4: Annual rainfall anomalies calculated from the Nicholson rainfall index

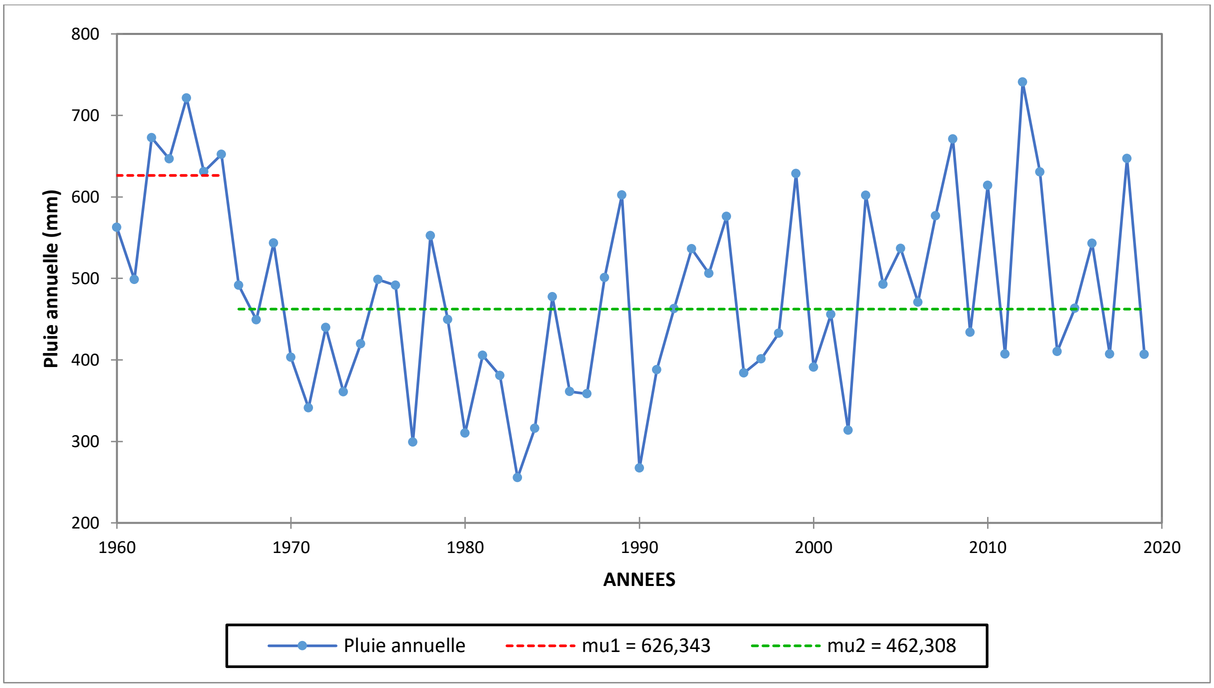


Figure 5: Standard Normal Homogeneity Test (SNHT) applied to annual rainfall averages.

Figure 4 shows that the first part of the positive trend in anomalies extends over 11 years. During this period, the number of years with excess rainfall is 9 including the first 8 successive years. In the second part of the overall negative trend in rainfall anomalies, 23 out of 35 years are deficit and 12 positive, including three successive years (1993, 1994 and 1995). The third part of the trend in rainfall anomalies, which is positive, extends over the last 15 years. Over this period, the number of years with excess rainfall is eight (8). This latest trend indicates a resumption of rainy periods.

In addition, the Normal Standard Homogeneity Test (SNHT) detects a downward break in the annual rainfall series from 1960 to 2019 (Figure 5). This break occurs in 1966 and the drop in the annual rainfall average before and after this date is 26 .1%. The risk of rejecting the null hypothesis (H0) even though it is true is less than 0.62%. So the break is significant.

2.2 Distribution of rainfall during the rainy season

The spatio-temporal distribution of rainfall within a season is a relevant indicator of rainfall trends. In the circle of Diéma, the rains are experiencing an evolution in their distribution, both in time and in space from 1960 to 2019. In fact, 369 out of 420 farm managers surveyed, i.e. 87.9%, affirm that the distribution rainfall is poor (Figure 6).

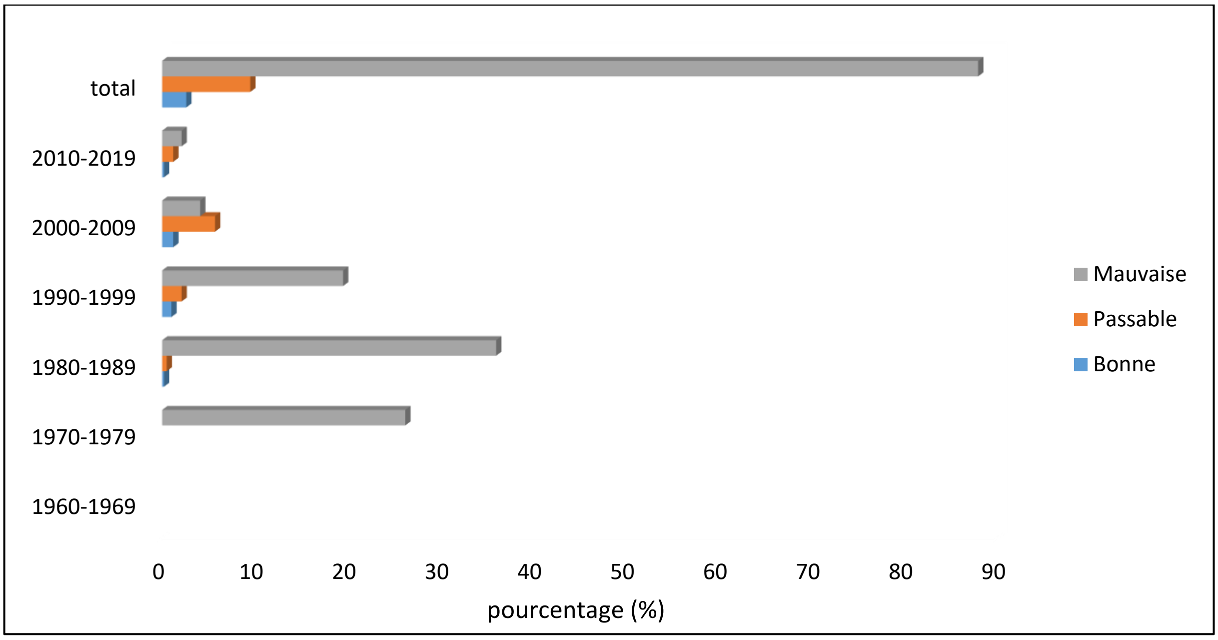


Figure 6: Population perception of the distribution of rainfall during the rainy season from 1960 to 2019

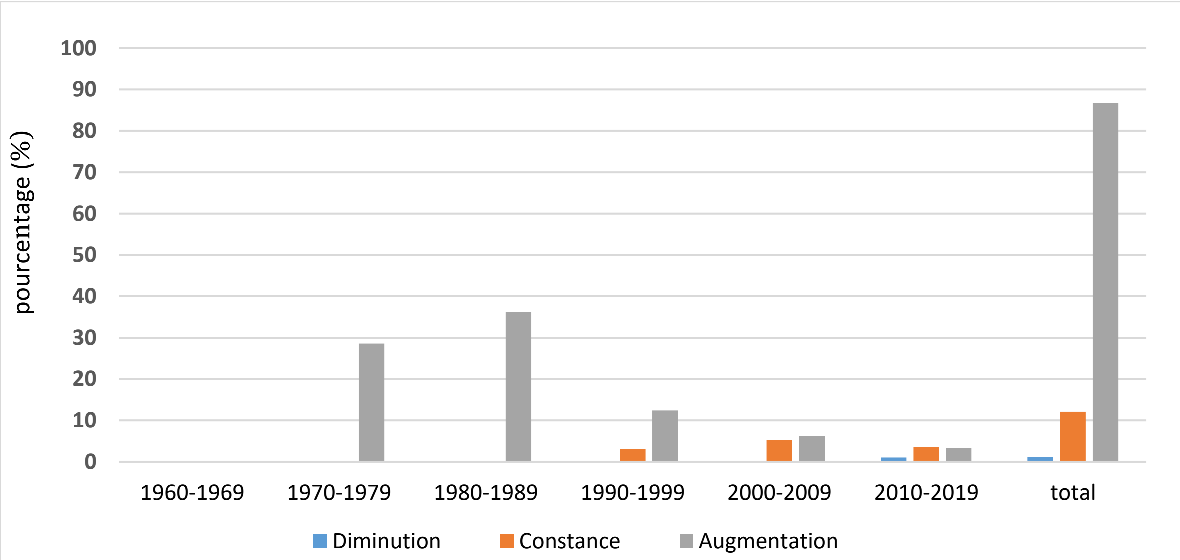


Figure 7: Farmers' perception of the evolution of the duration of dry spells between 1960 and 2019

Clearly, according to the farmers, rainfall is characterized by great spatio-temporal irregularity which began especially from the 1980s. This seems to explain the diversity of responses from respondents on this question, given that at the same time, one locality recorded a good rainfall rate unlike its neighbors.

This irregularity of rain explains the dry sequences (pockets of drought) which appear in the Diéma circle. A dry pocket being defined as a consecutive period of days without any rainy event, it can be short, long and normal respectively [9]. The pocket of drought is said to be short when 5 to 7 consecutive days go by without rain. It is called normal when 7 to 10 consecutive days go by without rain and it is called long when the number of consecutive days without rain is greater than 10 days.

On this question, 364 out of 420 UPA heads surveyed, or 86.7%, maintain that dry spells are increasingly longer in the Diéma circle, that is to say their duration is increasing (figure 7).

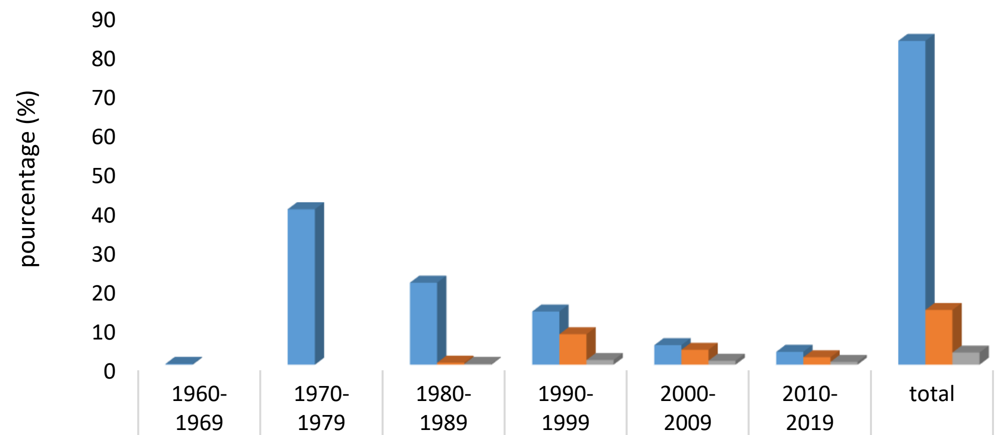
2.3 Evolution of the duration of the rainy season

The duration of the rainy season is an indicator that characterizes the evolution of rainfall. In the Diéma circle, a trend towards a shortening of the rainy seasons from 1960 to 2019 is noted by farmers. In fact, 82.4% of people surveyed say that the duration of the rainy season is decreasing.

The duration of the rainy season depends on the occurrence of its start and end dates. In the Diéma circle, the reduction in the duration of the rainy season (figure 8) is explained by a later start and an earlier end. Indeed, regarding:

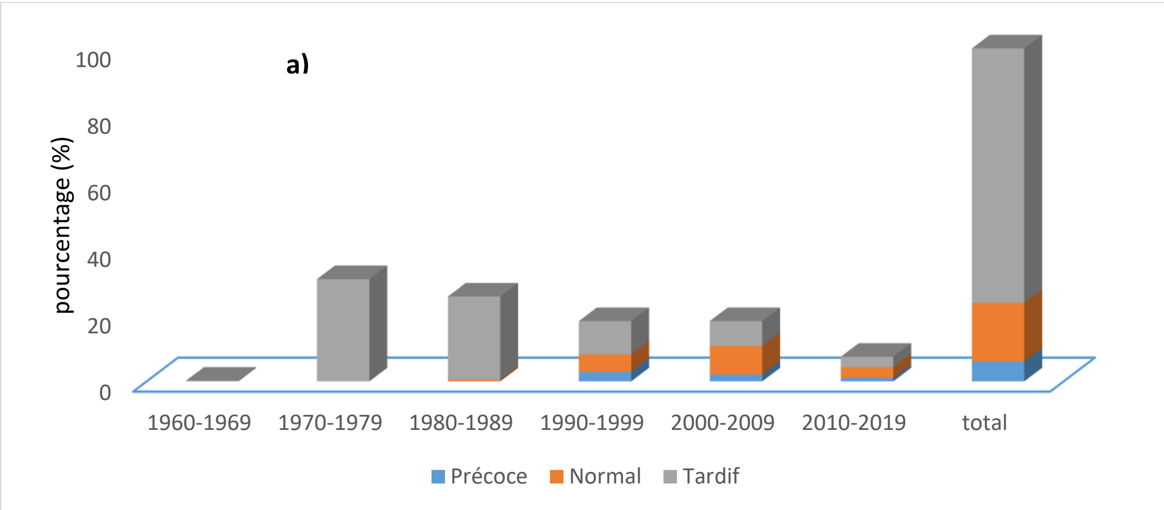
- the start date of the rainy season, it is perceived as late by 76.4% of the farm managers surveyed (figure 9a). This late start began especially from the 1970s.
- the date of the end of the rainy season was noted as early by 72.1% of the UPA heads surveyed (figure 9b). These premature cessations of the rainy seasons began in 1970.

In addition to what farmers think, meteorological data shows that between 1981 and 2019, the beginnings, ends and duration of rainy seasons have changed significantly. Indeed, the average start dates of the season were June 19 and June 24 respectively for the reference period 1981-2010 and the period 2011-2019. Regarding the end of the season, it is around September 16, but it has migrated to September 20 for the period of 2011-2019. Finally, the duration of rainy seasons during these two reference periods shows a downward but not significant trend. In fact, this duration increased from 89 days in the period 1981-2010 to 88 days in the period 2011-2019.



	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	total
Diminution	0.2	39.8	21	13.6	5	3.3	82.9
Constance			0.5	7.8	3.8	1.9	14
Augmentation			0.2	1.2	1	0.7	3.1

Figure 8: Farmers' perception of changes in the length of the rainy season between 1960 and 2009



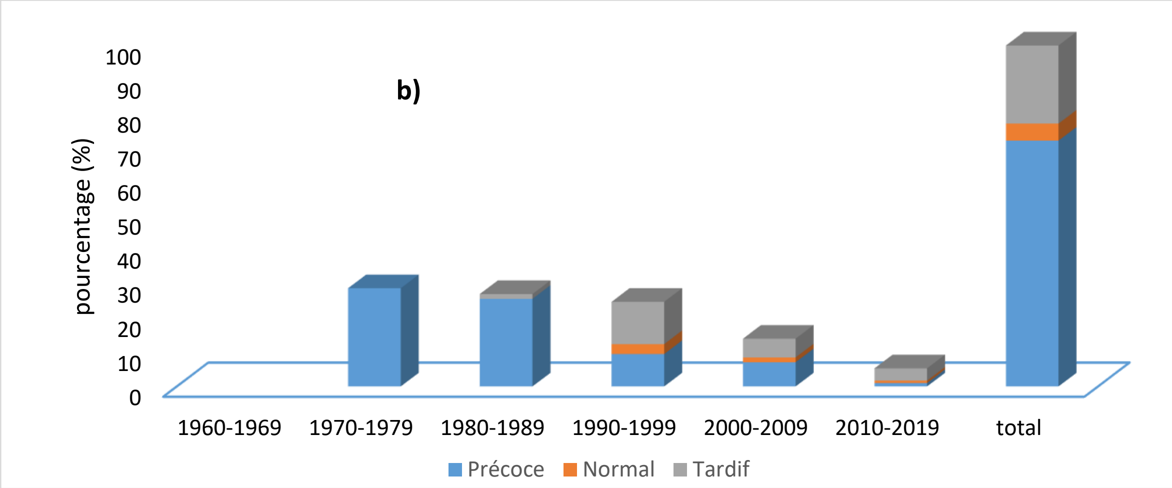


Figure 9: Farmers' perception of the start (a) and end (b) dates of the rainy season.

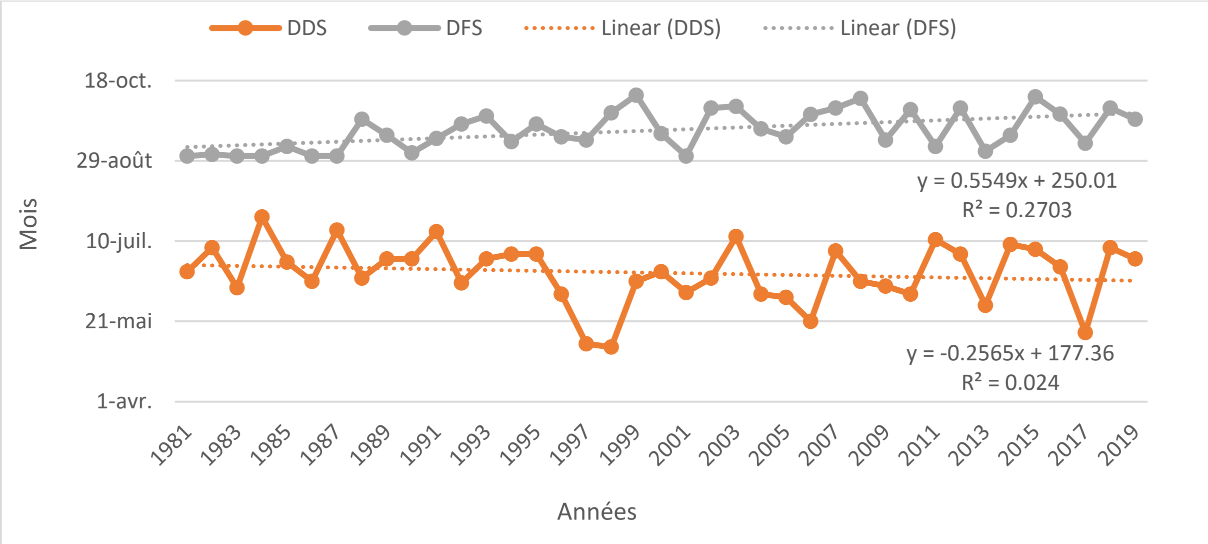


Figure 10: Evolution of start and end dates of the season

IV. Discussion of the Results

The results of our research show changes in rainfall over time in the Diéma circle. Similar results were obtained by researchers [10; 11].

First, the evolution of rainfall quantities in the Diéma circle is characterized by fluctuations. Moreover, a downward break was detected in 1966 in the annual rainfall series from 1960 to 2019. The annual rainfall average before 1966 was 626.3 mm and that after this date is 462.3, a drop by 26.1%. This situation corroborates the conclusions of the work of [12]. In addition, the Rainfall Anomaly Index (PAI) showed, generally speaking, three periods in the rainfall trend: a wet period from 1960 to 1969; a deficit or dry period from 1970 to 2005 and a wet period from 2006 to 2019. Other authors are in the same direction such as [13] who studied the rainfall in Kadial in the Inner Niger Delta, [14] student daily rainfall data from the Gouré station in Niger from 1936 to 2003 and [5] explaining the average annual rainfall from north to south in Mali.

Regarding the distribution of rainfall in the Diéma circle, our research reveals that rainfall is characterized by great spatio-temporal irregularity. Clearly, the precipitated quantities are poorly distributed in time and space, a phenomenon which began during the dry periods (1970s and 1980s). The poor distribution over time results in increasingly long dry sequences (more than ten days without rain), i.e. their duration is increasing. This phenomenon is mentioned in the conclusions of the work of [15] and [16].

As for the duration of the rainy season in the Diéma circle, it is characterized by a tendency to shorten especially from the 1970s depending on the population. This reduction in the duration of the rainy season is explained by a later start and an earlier end. This perception of the population is confirmed by the values of meteorological data showing that between 1981 and 2019, the beginnings, ends and duration of rainy seasons have evolved. This rainfall reality confirms the research results of [17] which manage to show that the average length of the rainy season decreases significantly on the Gourma mesosite between 1950 and 2007. Similar results were found by [18] in a study on a more global scale on Africa. On the other hand, other authors have qualified, if not refuted, the reduction in the length of seasons, such as [19] who do not find a significant trend in Mali.

V. CONCLUSION

The purpose of this research is to analyze rainfall disturbances in the context of climate change in the Diéma circle in Mali. To do this, a mixed methodology was used. In addition to the meteorological data, the questionnaire was administered to collect the quantitative data and the interview guide for the qualitative data.

The results reveal that rainfall is disrupted in the Diéma circle. Indeed, the annual rainfall amounts decreased substantially in the 1970s and 1980s. Thus, the annual rainfall decreased by 56 mm during the 1970s compared to the normal 1960 - 2019 and it decreased by 84.7 mm during the 1970s. decade 1980 compared to the normal 1960 - 2019. Moreover, a break in the series was detected in 1966 according to the Normal Standard Homogeneity Test (SNHT). Then, annual rainfall improved from the 1990s. In addition, the distribution of rainfall is poor and the duration of rainy seasons tends to shorten.

Furthermore, it is relevant to extend research to other climatic parameters to be able to carry out a holistic analysis of climate change.

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