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Influence of Climatic Variability on Seasonal Rainfall Patterns in the Poro Region (Northern Côte d'Ivoire)

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Abstract: ***In West Africa, in general, and in the Sahelo-Saharan zone in particular, socio-economic development is greatly influenced by rainfall variability. The Poro region, located in the Sahelo-Saharan zone, is also affected by the changing climate. The objective of this study is to characterize the influence of climatic events on seasonal rainfall patterns in the Poro region. The analysis of air temperature, relative air humidity, and variation of rainfall indices allowed us to characterize the climatic manifestation in the Poro region. Also, the comparison of monthly rainfall normal over the period 1901-2021 led to a good understanding of the behavior of seasonal rainfall patterns in the context of climatic variability in the study area. It is concluded that air temperature and relative humidity are factors in the temporal variability of seasonal rainfall patterns in the Poro region.***

Keywords: climatic variability, seasonal rainfall, SPI, Poro region

1. Introduction

The problems related to climate change are major concerns of our century. Several authors agree that water-related aspects will occupy a prominent place among the potential impacts of climate change (**Fougou et Abdourahamani, 2018; Gebrehiwot et al. 2019**). There is therefore a particular interest for scientists to study climate variability and water resources. Precipitation is the most important factor in climate for people and ecosystems. It's easy to measure. For these reasons, most studies and analyses focus on precipitation. Characterizing the impact of climate variability on seasonal rainfall patterns is therefore essential for proposing appropriate solutions for development projects. In West and Central Africa in general and particularly in Côte d'Ivoire, the issue of climate variability has been the subject of study by several researchers **(Kouassi et al. 2013; Meledje et al.2015; Kamagaté, 2019)**. It first affected the north of Côte d'Ivoire (Poro region) and then gradually spread to the whole country. These rainfall anomalies, which have been observed for nearly four decades, have had an exceptional impact on the Poro region. In fact, the whole of Côte d'Ivoire is highly vulnerable to rainfall deficits. In recent years, rainfall deficits have been noted in all regions, even the most humid. The most important issue, both for West Africa and other regions of the world, is the search for explanatory factors. This study aims to highlight the occurrence of droughts in the Poro region using the Standardized Precipitation Index (SPI), the Hanning 2nd order low-pass filter method and Pettitt. These tools provide a quick overview of phenomena as complex as hydroclimatic variability from annual rainfall recorded from 1901 to 2021 (115 years).

2. Materials and methods

2.1 Study area

The Poro region has the largest number of agropastoral lakes built in the north of Côte d'Ivoire. This region covers an area of 12,500 km², or 3.8% of the total area of the Ivorian territory. It is located between longitudes 5°16' and 6°16' West and latitudes 8°32' and 10°20' North (Fig.1) and belongs to the Bandama watershed. The climate of the area belongs to the tropical regime of the Sudan-Sahel type, whose seasonal rhythm is regulated by the movement of the Intertropical Front (ITF). The vegetation of the basin is essentially savannah. It consists of grassy savannahs, shrubs or trees. Gallery forests and open forests are also found.

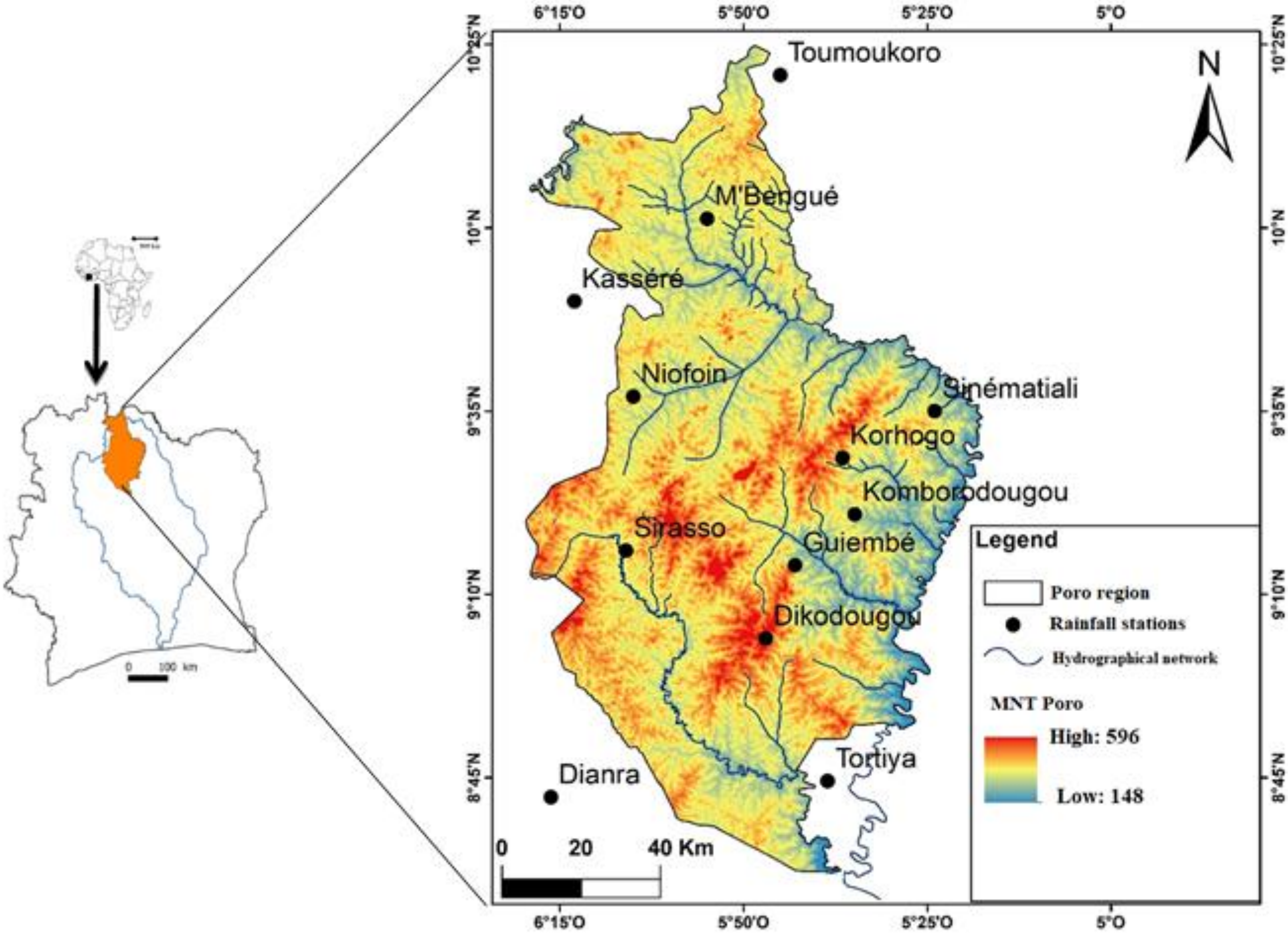

Figure 1: Location of the Poro region

2.2 Methods

2.2.1 Acquisition, analysis and critique of rainfall data

The data used come from the CRU (Climate Research Unit) database of the University of East Anglia in Norwich (UK). These are monthly rainfall amounts P (mm), average air temperatures T (°C) and relative humidity (mm). There are eight rainfall stations in the study area covering the period from 1901 to 2021. There are virtually no significant gaps in the data. By gaps we mean the unavailability of data for one or more months. These data were chosen because they have been studied in several studies and have yielded fairly satisfactory results. For example, the work of **Assoma (2013)** in the Agneby watershed showed a strong correlation between SODEXAM (Company of operating and Aeronautical and Meteorological Airport Development) data and CRU data. **Nka (2016)** also showed a strong correlation between data from several West African rainfall stations and CRU data.

2.2.2 Interpolation and mapping of rainfall

The ordinary kriging interpolation method was used to plot the mean rainfall curves. This allows the characterization of the spatial evolution of rainfall. Kriging takes into account the spatial variability and the regionalized variable, which allows it to minimize the estimation error. Several authors argue that kriging performs better than other interpolation methods **(Baillargeron, 2005; Le Lay, 2006)**. Simple kriging was performed using ARCGIS 10.2.2

2.2.3 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is calculated as follows by Eq. (1)**McKee et al.(1993):**

$$SPI = \frac{(P_i - P_m)}{S}$$

With P_i: the rainfall of month or year i; P_m: the average rainfall of the series over the time scale considered; S: the standard deviation of the series over the time scale considered.

The SPI values provide an indication of the extent of drought (or wetness) for each year in the time series **Ali et Lebel(2009)** (Table 1). Negative annual values indicate dryness relative to the selected reference period and positive values indicate wetness.

Table 1: Classification of drought in relation to the value of SPI

SPI classes	Degree of dryness
SPI > 2	Extreme humidity
1 < SPI < 2	high humidity
0 < SPI < 1	Moderate humidity
-1 < SPI <0	Moderate drought
- 2 < SPI < -1	Severe drought
SPI < - 2	Extreme drought

2.2.4 Detection of breaks in time series

To complete the drought analysis performed with the SPI, we applied the Hanning low pass filter method and PETTITTT test (Pettitt, 1979). This filter was for the detection of possible breaks. The Khronostat 1.01 software developed by the French Institute of Research for Development (IRD) was used.

3. Results and Discussion

3.1 Results

3.1.1 Study of rainfall in the Poro region

The annual rainfall collected at the eight stations in the study area show greater interannual variation to the west of the Poro than to the east. The spatial distribution of precipitation is characterized by an increasing gradient from north to south (well-marked) and a decreasing gradient from west to east (smaller) (Fig. 2).

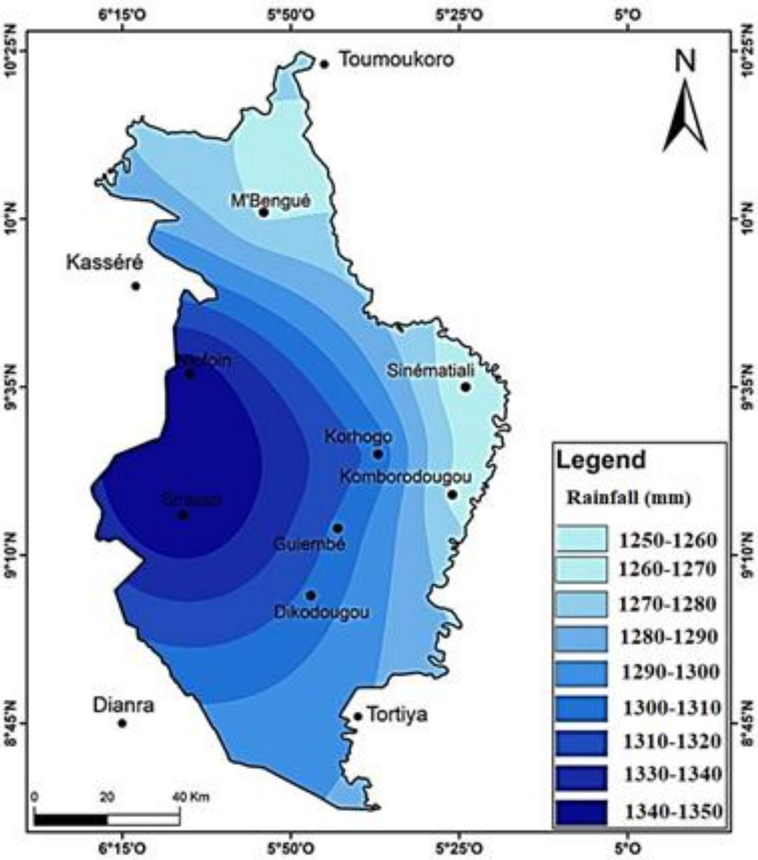

Figure 2: Spatial distribution of annual rainfall in the Poro region (1901-2021)

3.1.2 Spatio-temporal variability of rainfall

Figure 3 highlights the spatial variability of monthly rainfall from 1901 to 2021 in the Poro region.The analysis of results shows high rainfall values in June, July, August and September. The recorded rainfall varies between 140 and 170 mm for June, 180 and 260 mm for July, 240 mm and 300 mm for August, and 210 and 260 mm for September. Thus, the results indicate that in the region, the maximum of rainfall is reached in August. From October, a decrease in rainfall is recorded while remaining higher than that of November to March. The North-South gradient of the rainfall is less marked (almost homogeneous) and it is the same class of rainfallover the period from November to April corresponding to the great dry season in the region. From April to May, it is the resumption of rainfall in the region. The results show that the rainfall varies between 71 and 100 mm for the month of April, and 110 mm to 130 mm for the month of May. Whatever the considered month, the central and southern part of the region receive the highest amounts of monthly rainfall.

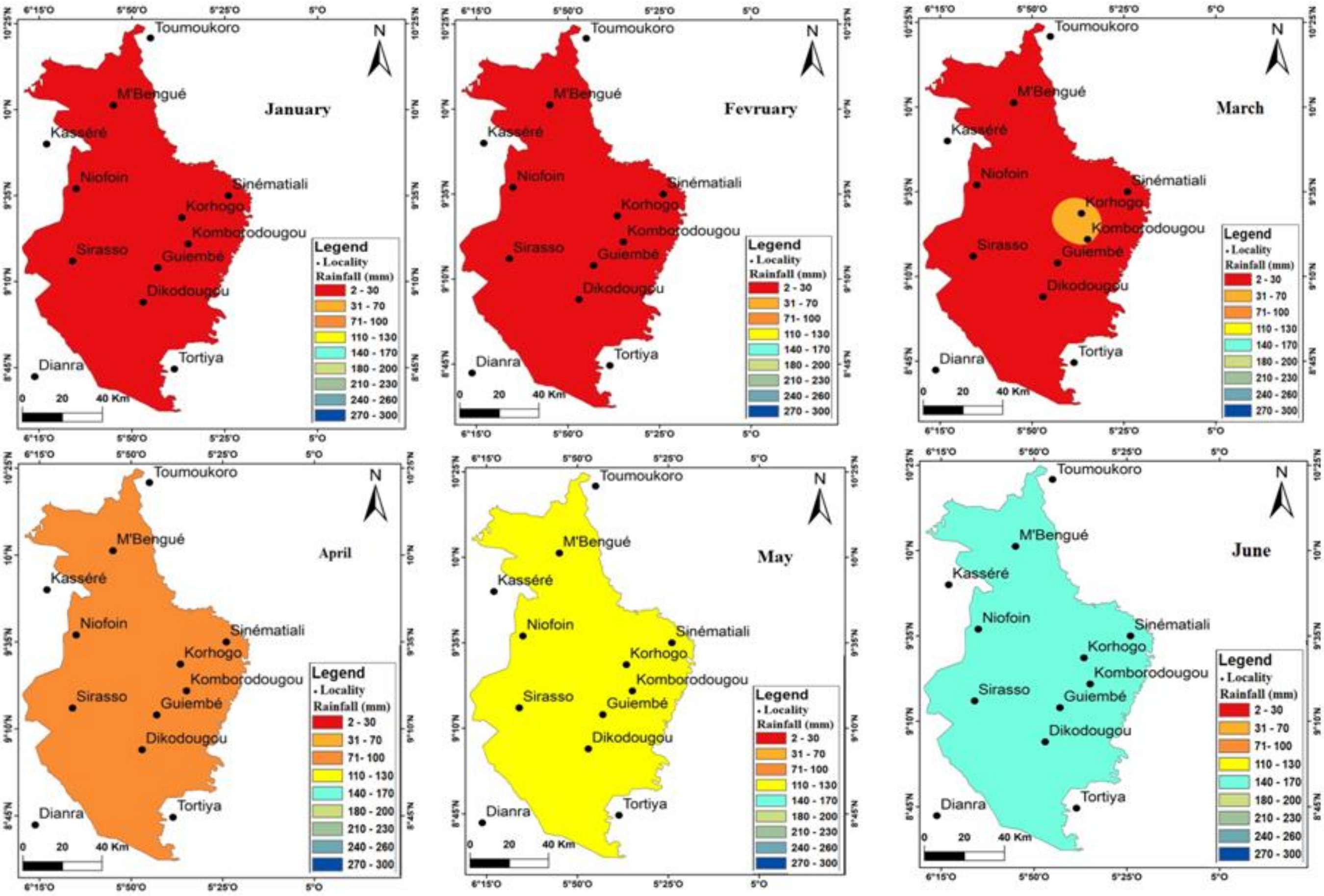

Figure 3: Spatial distribution of monthly rainfall in the Poro region (1901-2021)

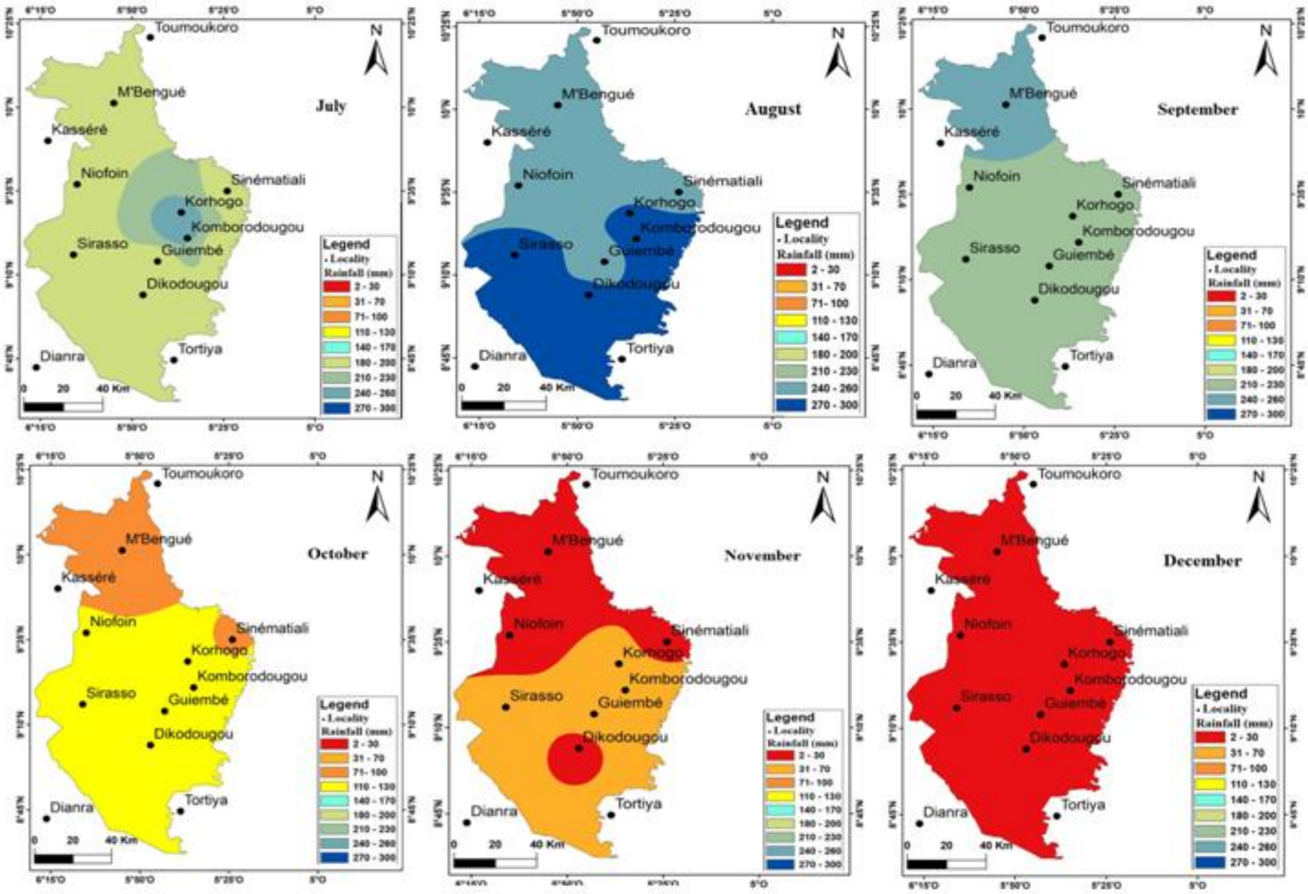

Figure 3: Spatial distribution of monthly rainfall in the Poro region (1901-2021)

3.1.3 Application of the Standardized Precipitation Index (SPI)

The analysis of rainfall in the Poro region indicates that the study area is mainly dominated by drought. The average values of the SPI are generally positive over the period 1901-1970 (2.69), while they are negative over all the following decades, with extreme values of -0.27 in 1971-2006 and - 0.62 in 2007-2021 (Table 2).

Table 2: Annual mean values of the Standardized Precipitation Index (SPI) (1901-2021)

Parameters	Wet periods	Dry periods	
Years	1901- 1970	1971-2006	2007-2021
Maximum	2.69	-0.27	-0.62
Minimum	1.22	-2.38	-2.43
Standard deviation	0.79	0.52	0.68
Arithmetic mean deviation	0.64	0.41	0.51

Taking into account all eight stations and all years over the period 1901-2021, moderate wet conditions prevail in more than 30% of cases, high humidity occurs in 12.94% of cases and extreme humidity occurs in 2.79% of cases over the same period (Table 3). Moderate drought occurs in 38.67% of cases over the period 1901-2021 (Table 3) and is dominant in the study area. The climate crisis in the Sudano-Sahelian zone has so far manifested itself in an increase in moderate to severe droughts and not in extreme droughts.

Table 3: Average frequency value (in % of stations/years) of the Standardized Precipitation Index (SPI) classes (1901-2021)

SPI Classes	Degree of dryness	Series average (1901-2021)
SPI > 2	Extreme humidity	2.78
1 < SPI < 2	high humidity	12.94
0 < SPI < 1	Moderate humidity	30.44
-1 < SPI <0	Moderate drought	38.67
- 2 < SPI < -1	Severe drought	12.75
SPI < - 2	Extreme drought	2.36
Total		100

Figure 4 shows the evolution of the annual average values of the SPI over the period 1901-2021.

In the Poro region, the rainfall stations are well distributed. From 1901 to 1970, the rainfall index is positive on all the stations. Then, rainfall becomes almost systematically deficient from 1970 to 2021 despite the appearance of a few surplus years. This deficit is particularly accentuated during the 1980s.Towards the end of the observation period, the rainfall remains deficient, but the values of the index rarely drop to "-1", while positive valuesare less frequent. Figure 4 shows also the rainfall deficit and surplus years. From 1969, the deficit years become veryrecurrent. The successive frequency of the reversal of rainfall trends explains the advent of the drought cycle in the Poro region.

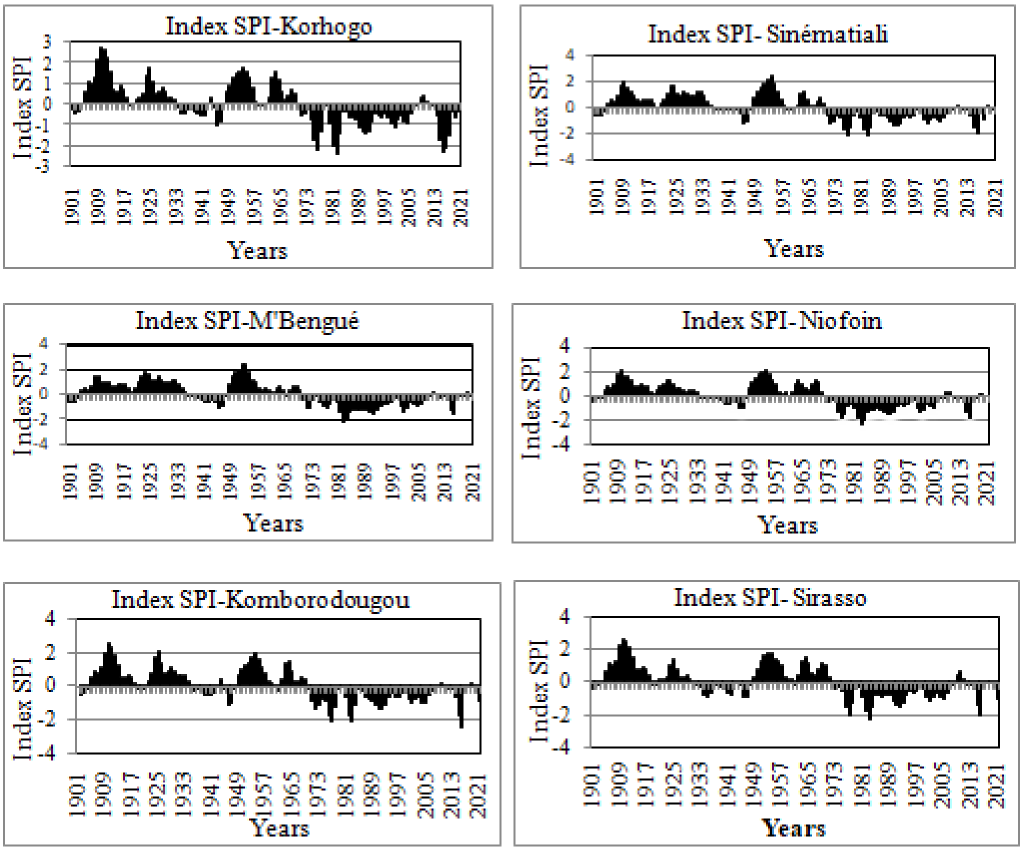

Figure 4: Annual values of the Standardized Precipitation Index (SPI) (1901-2021)

3.1.4 Analysis of annual flows

In the tropical zone, flows are linked to rainfall pulses, and the transfer can be subject to various modalities depending on the size, configuration, relief, geology and soils of the basin. The increase in flows is due to the improvement in rainfall, which nevertheless remains very fluctuating from one year to another, so that the tendency to replenish resources remains very uncertain and makes it more difficult to forecast availability. Figure 5 shows a fluctuation in average annual flows. The Bou station records 500.94 m^3/s while at the M' Bengué station, the average annual flow represents only 16.5 m^3/s.

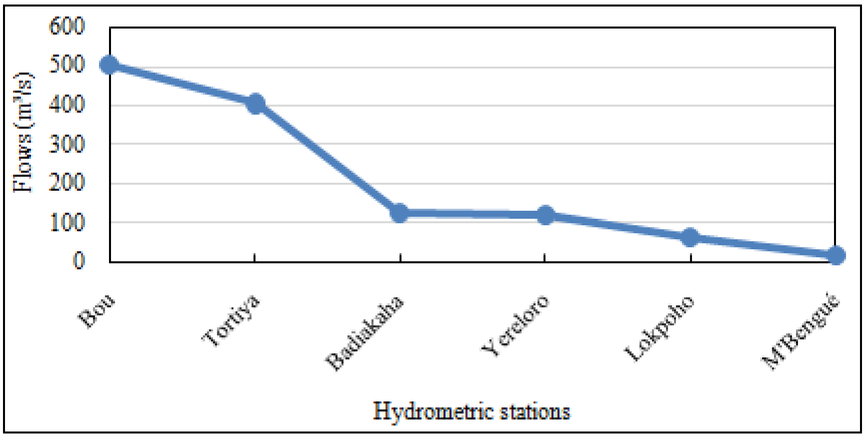

Figure 5: Average annual flows from hydrometric stations in the Poro region (1974-2015)

3.1.5 Synthetic analysis

The decrease in rainfall in the Poro region is followed by a decrease in the water levels of the rivers. The average annual flow of rivers has been in a continuous downward cycle since the beginning of the last century, which explains the supply regime of the rivers. This regime is unimodal because of a single rainy season. Rainfall is decreasing at the same time with relative humidity as temperature is rising.

In addition to the downward trend in long-term flows, the hydraulic regime of rivers is characterized by its high inter-annual (from one year to another) and annual (from one month to another and during the same year). The jagged evolution of climatic factors and average annual flows refers to that of rainfall (Fig. 6). Whether we are in a dry or wet sequence, a year of high hydraulicity can be followed by a year of severe deficits. We are in the domain of unpredictability.

Through these results, we can see that from 2001 there is a drop in relative humidity, average rainfall and average flow. This situation of lower hydrological inflows mainly explains the advent of a new cycle of drought.

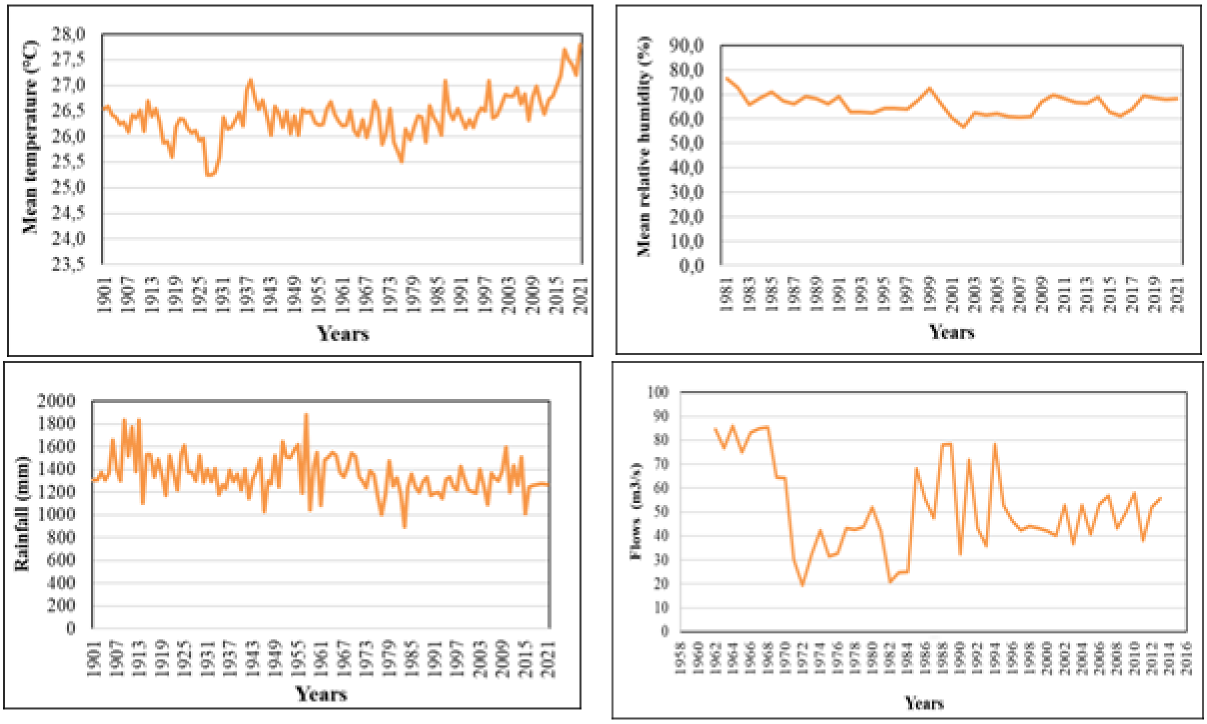

Figure 6: Change in the average a) temperature, b) relative humidity, c) rainfall, and d) flow

3.2 Discussion

The cartographic representations and the different statistical methods have made it possible to highlight the general downward trend in rainfall in the Poro region from the 1970s, which worsened over the following decades. However, the entire region was not affected equally given the influence of local climates. This result is in agreement with the results of the statistical tests applied to the annual rainfall. A drop in relative humidity and an increase in air temperature manifest climate variability. It severely affects the hydrological cycle. In tropical forest regions where the forest surfaces are very extensive and sensitive to surface conditions, atmospheric humidity has a marked continental origin **Fontaine et Janicot (1992)**. Increasing dry surfaces should cause air temperatures to rise through heat transfer.

According to **Sultan et al. (2001)**, the decrease in forest cover, which naturally absorbs carbon dioxide contained in the atmosphere, will contribute to increasing the atmospheric content of this greenhouse gas. The climatic variability observed in the Poro region is partly linked to the decrease in the frequency of rainy days in general and to the daily rains of the rainfall heights in particular. Indeed, the decrease in the frequency of rainy days is synchronous with that of the annual rainfall heights. The studies of **Paturel et al.(1998)**, **Servat *et* al.(1999)**,**Bodian et al. (2011), Diallo et al. (2013),Hounkpè et al. (2016), Badou et al. (2017)**and **Emmanuel et al. (2019)** showed that the number of rainy days has decreased in West Africa while seems to be more stable over Central Africa. It appears that the temperature and the relative humidity of the air are factors of the temporal variability of the seasonal rainfall regimes in the Poro region. Indeed, these atmospheric parameters strongly influence the spatio-temporal distribution of rainfall. However, the previous results of the study show a drop in rainfall and relative humidity while there is an increase in average temperatures during the same period in the region. Based on these observations, it can be said that the variability of seasonal rainfall patterns in the Poro region depends on the one hand on the drop in relative humidity and on the other hand on the rise in air temperature.

In a perspective of the increase in air temperature, we are entitled to fear a change in seasonal climatic patterns in the region. The results obtained can be linked to other works in the world. According to the results of the work of **Richard *et* al. (2002)**, El Niño events after 1970 are part of a warm series with very high amplitudes. According to the same author, on the Southern Africa window, the effects of the drought have become more accentuated and extended in space. These results can be related to the increase in the magnitude of the variations described around 1970.

4. Conclusion

The treatments highlight a persistent decrease in rainfall over the 1970s, 1980s and 1990s compared to previous years (1901-1969). According to the results from SPI, the drought generally retains a moderate character and is only very rarely extreme in the Poro region. Thus, this work provided an idea of the potential impacts of climate change on the evolution of precipitation in the Poro region. The hydrological data indicate a change in runoff and precipitation. This hydrological drought must have caused an earlier and faster emptying of groundwater **(Mahé et al. 1998).** This phenomenon has been described by some Ivorian authors including **Savane et al.(2001)** at the Flampleu station in the Cavally basin, **Saley (2003)** in the western mountainous region and **Kouassi et al.(2010)** in the N'zi basin. It appears that the hydrological drought is still effective, even if it if it has diminished in recent years.

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Conflict of interest: The authors declare that they have no conflict of interest.

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