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Characterization of Climatic Variability in the Downstream Gambia River Basin: Cartographic Approach Using the E-Nexus Module

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Abstract— *The variability of climatic conditions has become a major concern in recent decades because of the damage it continues to cause to the environment and human activities. The aim of this study is to analyze the spatio-temporal variability of climatic parameters, in particular precipitation and temperature, in the lower Gambia River basin. It is being carried out using the E-NEXUS module, a high-performance tool for analyzing climate variability in a watershed. To this end, rainfall (CHIRPS) and temperature (ERAS) data for the study basin, dating from 1980 to 2019, have been collected and processed through several indexes of the tool : rainfall deficits and return periods, standardized rainfall indices, drought indices, heat value. The results show significant spatio-temporal fluctuations in precipitation, temperature and drought in the basin. Indeed, significant rainfall deficits were recorded in 1981 and 2019. For a return period of a decade, these shortfalls range from 250 to 300mm in the area of the Banjul, Jenoi, Toubacouta, Kaolack and Nioro stations. These deficits can reach 350mm with a return period of 20 years. Between 1981 and 2000, severe drought prevailed, while between 2000 and 2019, the drought became moderate. The drought affects the northern Sudanian zone of the basin. Heat waves exceeding 45° in April in the northeastern part of the basin are a notable occurrence, especially in the last decade of the series: 2019 and 2016 record the most significant heat waves. Climatic variability in the study basin is significant, as evidenced by a sharp drop in rainfall from the northern Sudanian zone to the southern Sudanian zone, and the occurrence of waves, particularly during the last decade of the study.*

Keywords— *Rainfall variability -E-Nexus - heat wave - Gambia River.*

I. INTRODUCTION

1. *Context*

Because of the immediate and long-term damage it is causing to the environment, to economic activities and, in short, to the future of mankind, climate change is increasingly becoming a concern that fuels scientific debate and research. Indeed, since 1968, the climatic situation of the West African window has been marked by repeated drought, which was exacerbated in the 1970s and 1980s (Dione, 1996). This drought is generally perceived more in terms of impacts than genesis, but scientific and technical data alone do not always seem to be sufficient to make perceptible the dramas experienced by populations in regions affected by the vagaries of the climate (herd losses, crop failures, famines, population displacements, malfunctions in filling reservoirs, etc.) (Faty, 2019). In addition, climatic variability in this region is reflected in a drastic drop in river flows and the salinity front, which is steadily advancing upstream of river mouths in estuary basins such as Senegal, Gambia, Casamance, ect. The Gambia is a West African river that is undergoing profound changes in its hydroclimatic dynamics (Dionne 1996; Lo, 2000; Konaté 1997, etc.). Thus, in this basin, the variability of climatic conditions is becoming increasingly significant and poses more and more problems for water resource management.

While the understanding and characterization of climate variability at small scales are still fundamental to understanding the impacts of climate change, local vulnerability and for development projects (Maléki, 2014), the inadequacy of ground-based measuring instruments and the particularly dubious and flawed nature of the little data collected to date have long been limitations to research and apprehension of the issue in West African river sub-basins. In this context, the use of new approaches and satellite data is increasingly essential to meet the challenge of understanding climate change in these basins. In the estuarine river basin, climate characterization remains problematic due to the lack of climate data. This study therefore uses satellite data on rainfall and temperature, processed by E-Nexus software, to assess the spatio-temporal variability of climate in the downstream Gambia basin.

2. *Presentation of the downstream Gambia river basin*

The Gambia is a West African river stretching 1150 km from the Fouta Djallon mountains in the Republic of Guinea to its mouth in Banjul (Gambia). The river forms a watershed of 77,054 km2, essentially divided between Senegal, Gambia and the Republic of Guinea. Its estuary is 520 km long and forms a downstream or estuarine basin of 32,500 km2. This downstream basin, the study area, is bounded :
- to the north by the Saloum estuary basin (Senegal),
- to the south by the Casamance estuary basin (Senegal),
- to the east by the continental basin, the purely fluvial domain of the Gambia River,
- and to the west by the Atlantic Ocean.

Rainfall in the study area ranges from 500mm in the northern Sudanian zone to 1,200mm in the southern Sudanian zone. The basin is populated by a Senegalese-Gambian community engaged in agriculture, livestock breeding and fishing.

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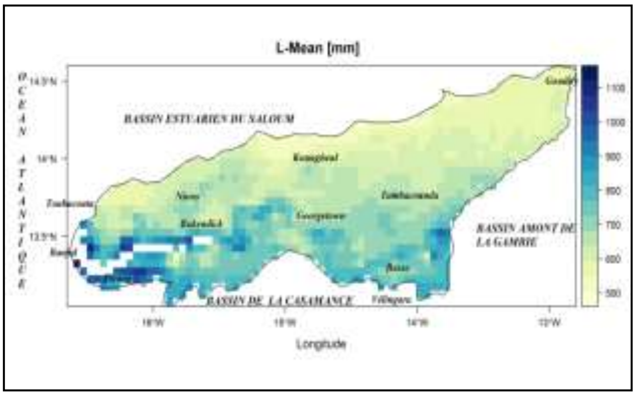

Fig. 1: Location of the downstream Gambia River basin

II. Data and Methods

The E-nexus cartographic approach provides a spatialization of the study's climatic parameters. The module uses satellite data. We downloaded them from http://chg.geog.ucsb.edu/data/chir https://cds.climate.copernicus.eu/in NetCDF(.nc) file format.

1. Study data

The data collected to carry out this study are in particular :

- climate hazards group infrared precipitation with station data (CHIRPS), which are the daily precipitation data available for the period 1981-2019;

- ERAS data, relating to basin temperatures and, like precipitation, available for the period 1981-2019.

E Nexus is a software package that includes a module for characterizing climate variability. This module is particularly robust for processing and spatializing climate parameters. It has been used in particular in the Senegal River basin, which borders on the Gambia basin.

2. Methods

Data pre-processing is the initial step in ensuring full compatibility of input data formats with the E-Nexus module. By attaching the shapefile of our study catchment, pre-processing also enables us to crop the rainfall and/or temperature data relating to our study catchment. The daily input data analysis process produces our monthly and annual aggregations.

a. Annual rainfall deficits

For this operation, we calculated the annual rainfall deficits in the downstream basin of the Gambia River according to return periods of 10 and 20 years. This is achieved through the property that the event x with return period T is defined as the event that occurs on average after T years since the last record and is the inverse of the probability of the annual occurrence of x. So, if P is the cumulative rainfall distribution function, the return periods for rainfall deficit or excess are calculated as follows:

$$= \frac{1}{P}$$

$$T_{excess} = \frac{1}{1-P}$$

The operation provides a variety of cartographic results according to several parameters: excess/deficits, L-CV variation, skew coefficient and Kurtosis coefficient. For this study, we have highlighted rainfall deficits, which are spatialized in percentage (%) and absolute value (mm), according to the Person III distribution.

b. Standardized Precipitation Index (SPI)

SPIs enable us to detect spatiotemporal rainfall anomalies in the study basin. For this purpose, we used the SPI anomaly classes defined by Mc Kee et al, 1995 and Agnew et al, 2000. A drought episode occurs whenever the SPI is continuously negative and reaches an intensity of -1.0 or less.

TABLE 1: SPI anomaly intensity class (Mc Kee et al, 1995 and Agnew et al, 2000)

Wet /dry class	SPI values (McKee et al)	SPI values (Agnew et al)
Extremely dry	< -2	< -1.64
Severely Dry	[- 2, -1.5)	[-1.64, -1.28)
Moderately Dry	[-1.5, -1)	[-1.28, -0.84)
Moderate	[-1,1)	[-0.84, 0.84)
Moderately Wet	[1,1.5)	[0.84, 1.28)
Severely Wet	[1.5,2]	[1.28, 1.64]
Extremely Wet	>2	>1.64

c. Dry Spells

Dry Spells are calculated using the Mann-Kendall statistical test (Man 1945 and Kendall 1975) and the Sen method (1968). The tests involve evaluating a possible trend in a time series, which will reject the null hypothesis Ho (No trend). From a succession of n values of xi, the S statistic is represented as follows :

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i)$$

From here, a positive (negative) value of S indicates an overall increasing or decreasing trend. By changing, the order of succession, we obtain a total of n (n-1)/2 different combinations, with the S factor having a variance [6] of :

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5)}{18}$$

The Z distribution associated with the trend is calculated as follows:

For the Sen method, the presence of a trend is assessed by considering the series as a succession of Xi values. The slope coefficient can therefore be obtained using the following expression:

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$$Z = \begin{cases} \frac{(S-1)}{\sigma} & (S > 0) \\ 0 & (S = 0) \\ \frac{(S+1)}{\sigma} & (S > 0) \end{cases} \qquad \beta = Median\left(\frac{X_j - X_i}{j - i}\right), \quad j > i$$

To have a non-null hypothesis with 95% confidence, you need a Z value greater than 1.96.

d. Temperature indices

Temperature indices are studied here through heat waves and return periods. Heat waves are studied over the period 1980 to 2019, with return periods of 5, 10 and 20 years. To detect heat waves, the Heat Wave Magnitude Index (HWMI, Ceccherini, 2017 and Russoetal, 2015) method was applied. The HWMI consists of aggregating temperature excesses above the threshold defined to indicate a heat wave: A heat wave is thus defined as a sequence of 3 or more days during which the daily maximum temperature is above the 90th percentile of maximum temperatures over a 30-day window surrounding the execution of that day during the reference period, which here is from 1981 to 2010, i.e. 30 years. The daily magnitude is calculated as follows:

$$M_d(T_d) = \begin{cases} \frac{T_d - T_{30y25p}}{T_{30y75p} - T_{30y25p}}, & T_d > T_{30y25p} \\ 0, & T_d \le T_{30y25p} \end{cases}$$

Where T is the maximum daily temperature and $Td \le T30y25p$, the 25th and 75th percentiles of the maximum daily temperature of all 3 to years observed.

III. Results and Discussions

Rainfall in the study basin ranges from 500 to 1100mm, with an average of 800mm. In other words, the basin is divided between the northern Sudanian zone and the southern Sudanian zone. However, rainfall is highly variable in space and time between 1981 and 2019. Significant rainfall deficits were also noted during this period in the north of the basin.

Annual precipitation deficits in the basin

Annual rainfall deficits, calculated over 10-year and 20-year return periods, show that rainfall in the study area is most deficient in the west and north of the basin. In other words, these deficits are recorded in the localities of Banjul, Bakendick, Pirang, Nioro and Tambacounda, where their relative values for a one-decade return period vary between 22 and 26% (fig. 2c); they are, however, concentrated in the zone under maritime influence, reaching 250 mm in Banjul and Pirang (fig. 2a). For a return period of two decades, rainfall deficits are even more significant. They affect the north, west and, to a lesser extent, the center of the basin. These deficits are higher for 20-year return periods: 250 to 300 in the north and west, or 32%.

Trends in rainfall anomalies (standardized precipitation indices) Standardized precipitation indices reflect a predominance of moderate drought in the study basin. In fact, 63% of years show at least one moderate drought. This meteorological drought is most prevalent in the period from 1981 to 1998. This period is dominated by moderate to severe drought. The most severe precipitation anomalies were recorded in 1990 and 1991, while 1983 was the driest year of the entire 1981-2019 period. In the phase from 2000 to the end of the series, rainfall anomalies are less frequent and less significant. This is particularly true of 2008, 2012 and 2015, when severe drought occurs at the start of the rainy season. In short, we can see that rainfall anomalies (drought) are notably recorded at the beginning and end of the rainy season (June, July, October). In other words, the trend is increasingly towards a shorter rainy season.

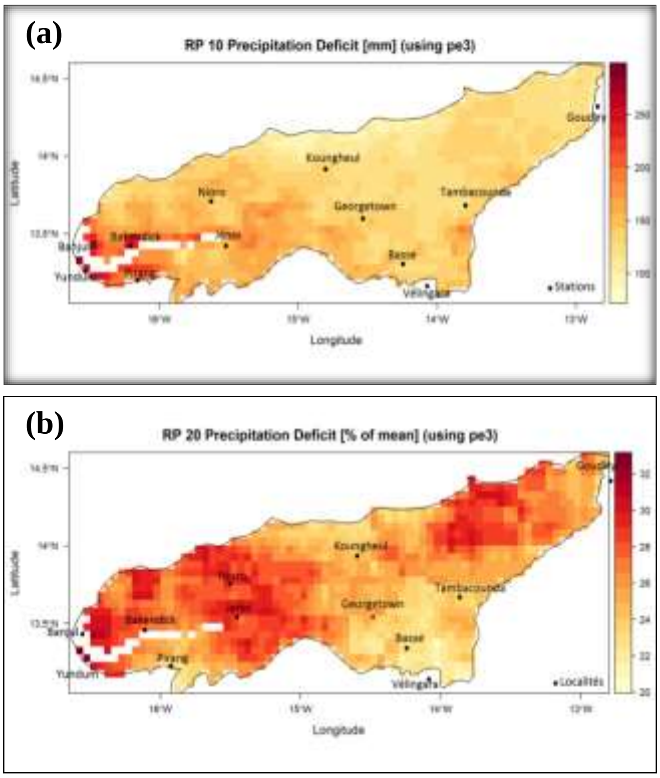

Fig. 2(a-b): Annual rainfall deficits for 10-year in mm (a) and 20-year return periods in % (b).

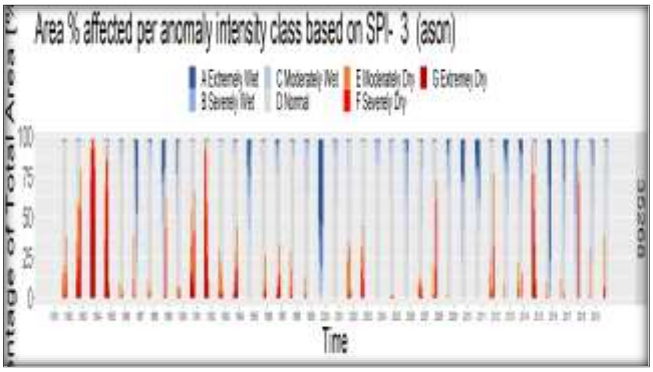

Fig. 2(c): Standardized rainfall indices in the lower Gambia River basin between 1981 and 2019

Drought indices in the downstream basin

Drought indices for the E-nexus module express the frequency and intensity of drought periods in the study basin. In fact, in the downstream Gambia basin, drought over the 1981-2019 period is most marked in the north and center of the

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basin (Koungheul, Nioro, Tambacounda, Goudiry, Bakendick, Jenoi).

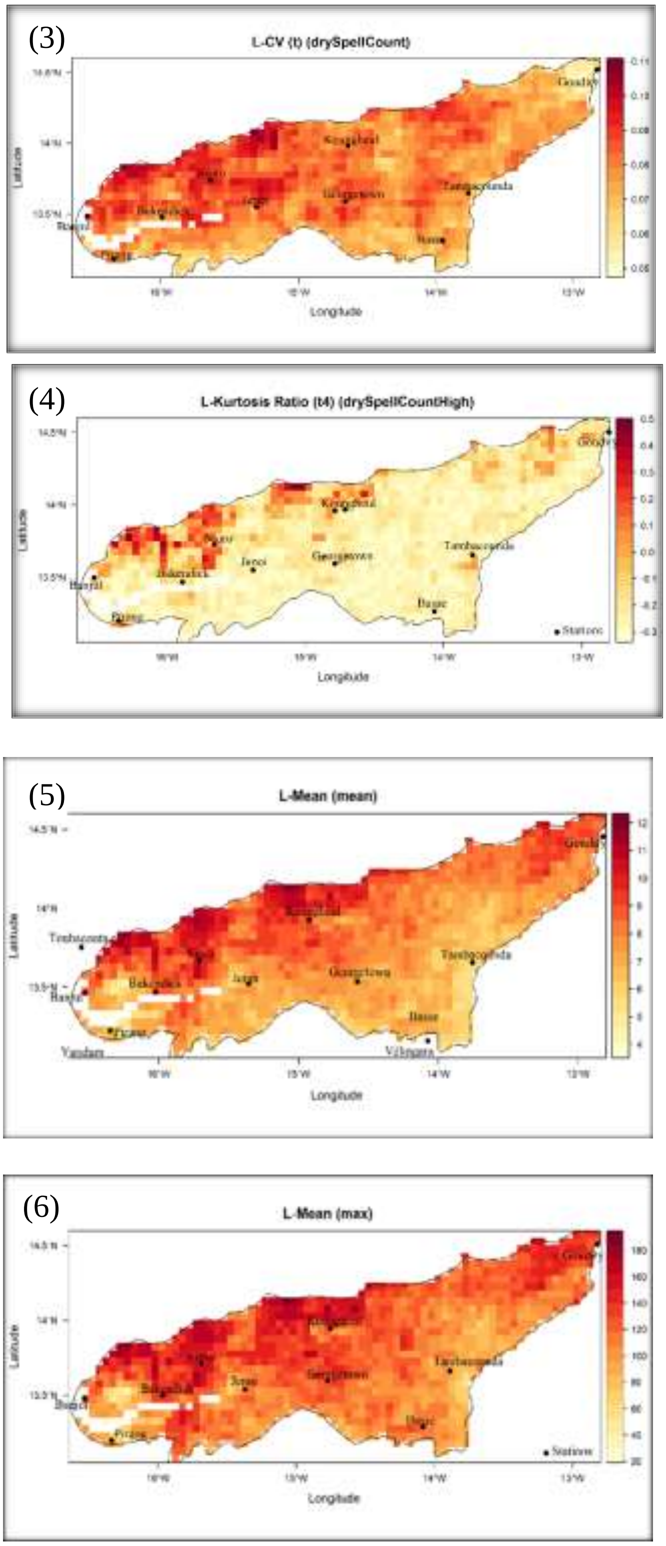

Fig. 3-4-5-6 : spatialization of drought indices in the basin

Temperature indices in the study basin

Temperature indices are studied through the occurrence of heat waves in the basin. In this study basin, most of the years observed show normal temperature behavior. However, heat waves have occurred in a number of years more than others: these include 2019; 2017; 2016; 2013; 2002. For these years, the heat wave amplitude index is variable in both space and time. This amplitude index is highest in 2019 in the basin's continental northern Sudanian domain (fig. 7, year 2019). Following the classification of Ceccherini et al, 2016, we note that in 2019 and 2016, the amplitude index expresses a very extreme heat wave north of Tambacounda and extreme in the areas of Koussanar, Koungheul, Kaolack. Overall, the heat waves that have impacted the basin remain localized in the northeast, in the Tambacounda region. However, despite its proximity to the ocean, the coastal area of the study has recorded heatwave episodes, the most significant of which occurred in 2017 and 1996. In other words, in this part of the basin covering the localities of Banjul and Bakendick, there is a preponderance of heat waves with extreme amplitudes.

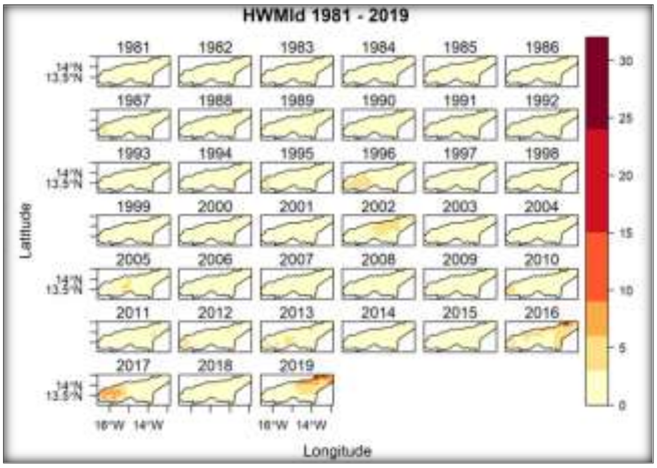

Fig. 7 : Heat wave amplitude indices

Heatwaves have their greatest impact in the continental North Sudanian area of the study. This area also has the highest number of years in which the heat wave amplitude index is greater than 4 (according to the classification of Ceccherini et al, 2016), i.e. expressing at least one extreme heat wave. Since 2010, the frequency of heat waves has increased, and their amplitude index has become increasingly important in the northern part of the basin. The more frequent occurrence of heat waves over the past decade reflects a rise in temperatures in the basin.

IV. CONCLUSION AND DISCUSSIONS

Using satellite data on rainfall and temperature, this study has demonstrated the occurrence of climatic variability in the northern Sudanian zone of the basin. The analysis highlights a climatic deterioration marked by a decrease in cumulative rainfall from 250 to 300mm in the northern Sudanian zone. Drought and heat waves are thus manifestations of climate change in the basin. This drought situation, with a southward shift in isohyets, dates from the late 1960s to the late 1990s. This observation has also been noted by several studies in West Africa: Bodian (2011), Faty (2018), Thiaw (2020).

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