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Spatial and temporal variation of rainfall from 1970 to 2016 in the lower Ouémé Valley in Benin.

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ABSTRACT

West Africa has experienced spatio-temporal variability in rainfall regimes for several decades, characterized by the increase in extreme weather events leading to floods and droughts. Benin is not immune to these hydrological and climatic fluctuations in terms of flood and drought hazards. Precipitation is an important variable in the hydrological cycle and has a strong influence on irrigated and rain-fed agricultural crops, therefore a direct impact managed wetland for agriculture. This study aims to analyze the spatial and temporal variation of precipitation over the period from 1970 to 2016 at 8 rainfall stations in the lower valley of Ouémé River Basin. The method used is based on the analysis of the variability and trends of the annual series of precipitation and temperature through three drought indices: the standardized precipitation index (SPI), the Palmer drought severity index (PDSI) and the hydrological drought index (PHDI). The results obtained with the three methods used show that it is reasonable to believe that the basin has retained unstable and poor rainfall characteristics over several decades. The estimated drought indices show that the lower valley of Ouémé River Basin has experienced in the past a long period of extremely severe and severely dry drought followed also by moderate droughts with relatively wet periods in most of the study area.

***Keywords* - climate, drought index, hydrological drought, Ouémé River Basin**

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I. INTRODUCTION

Drought is a natural phenomenon with insidious characteristics', resulting from insufficient precipitation compared to normal values. When it persists for a whole season or more, this insufficiency prevents adequate response to the needs of human societies and the environment (LABEE, 2015). It is one of the most important natural risks that have negatively impacted human societies through generations (Faye *et al.*, 2019). According to Wilhite and Glantz (Wilhite and Glantz, 1985), there are four categories of drought: (i) meteorological drought which is defined as a lack of precipitation for a period of time over the affected area; (ii) hydrological drought which is an insufficient supply of surface and groundwater; (iii) agricultural drought referring to a period of soil moisture deficit, which affects crops' productivity; and (iv) socioeconomic drought associated with insufficient water resources to satisfy economic needs in the affected region. Despite major achievements in science and technology and successes in the twentieth century, populations continue to suffer the consequences of the climate (Krysanova *et al.*, 2008) including drought. To overcome this risk, people have tried to appreciate the phenomenon and to understand climate cycles through the study of the variability and trends of different climate variables especially precipitations and temperatures (Faye *et al.*, 2019). Drought's prevention requires a detailed and specific analysis at regional River Basins' scales. Since 1900, several indices have been developed to identify and evaluate the severity of drought as well as to identify interactions between drought and hydrological/meteorological events (Baran *et al.*, 2017). Among these indices we can mention: the Standardized Precipitation Index (SPI); the Palmer Drought Severity Index (PDSI) and the Hydrological Drought Index. Developing a precise drought index is difficult because of the complexity of the relationships between hydro-climatic variables and drought. The indices proposed for the analysis of drought are mainly based on water balance calculations and they consider a type of drought, meteorological, hydrological or agricultural (Baran *et al.*, 2017). Each of the three drought indices mentioned above represent one of the different types of drought. Standardized Precipitation Index (SPI) is a measure of precipitation deficit, its use is widespread because it is based on the probability of precipitation at different time scales (McKee *et al.*, 1993). SPI has been widely used to monitor drought in many regions (Vicente-Serrano *et al.*, 2004),(Cancelliere *et al.*, 2007), (Raziei *et al.*, 2009), (Liu *et al.*, 2012), (Zhang *et al.*, 2013), (Mallya *et al.*, 2016).

Palmer's Drought Severity Index (PDSI) was developed in 1965 by (Palmer, 1965). It was intended to retrospectively look at wet and dry conditions from a water balance viewpoint. The PDSI has been shown to be very effective in determining long-term drought that is for several months, but less effective for short term conditions that last few weeks (Zargar *et al.*, 2011). The PDSI and its variations have been widely used for drought monitoring and to make decisions about water management more operational (Wells *et al.*, 2004), (Mallya *et al.*, 2016), (Karl, 1986),(Vicente-Serrano *et al.*, 2012). Some of the significant properties of PDSI and its variations have been studied by (Alley, 1984), (Heddinghaus and Sabol, 1991), (Karl, 1986), (Guttman, 1991), (Guttman *et al.*, 1992) . The Hydrological Drought Index (HDI) shows how the precipitation relates to actual evapotranspiration. It expresses the fraction of the precipitation that is evapotranspired and it is defined as the cumulative precipitation (Pcum) divided by the actual cumulative actual evapotranspiration (Eta), on a time scale of one month, expressed as a percentage (UNESCO-IHE, 2014). It is therefore a measure of the amount of water that remains available for deep percolation or surface runoff.

The African continent experienced during the 20th century a severe drought which affected many areas and caused colossal economic loss (Sylla *et al.*, 2016) (Mahaman Bachir and Savane, 2009).Several studies carried out in West and Central Africa have highlighted, based on 1970s, a decrease in surface and underground runoff following the decrease in rainfall (Faye *et al.*, 2018),(Faye, 2018), (Faye *et al.*, 2019). In Benin, according to the results of the work of (PNUD-PANA-BENIN, 2008), the main risks threatening the populations of Benin are floods and droughts. It should be added that since the end of the 1960s, climatic disturbances have occurred in Benin and manifested themselves in a reduction in the average annual amplitude of total rainfall amounts by 180 mm (Zannou, 2011). An intensification of the droughts which occurred during the same period, particularly in the 1970s and 1980s, was noted. In addition, the rains at the start of the rainy season are violent, which favors flooding and erosion on the land poorly protected soils (Olivier *et al.*, 2018). The objective of this article is to analyze hydro-climatic variability in the lower Ouémé valley. To do this we will carry out a comparative analysis between the values of the SPI, the PDSI and the PHDI. This study aims to analyze the impacts of years of severe drought and years of flooding Hydro-agricultural developments in the lower valley of the Ouémé.

II. STUDY AREA

The lower valley of Oueme River Basin is located between the parallels 7 ° 12 'and 6 ° 23' North and the meridians 2 ° 21 'and 2 ° 33' East. This is the part of the basin where a break in slope is obvious (Sossou-Agbo, 2013).This valley is served by the 510 km of Oueme river which is the largest river in Benin. The valley is nearly 50 km North-South long and about 25 km East-West wide. It consists of two distinct parts: a flood plain housed inside the valley and a upland overlooking the first part. These different parts cover an area of 1,236 km2 (Alimi et al., 2015).

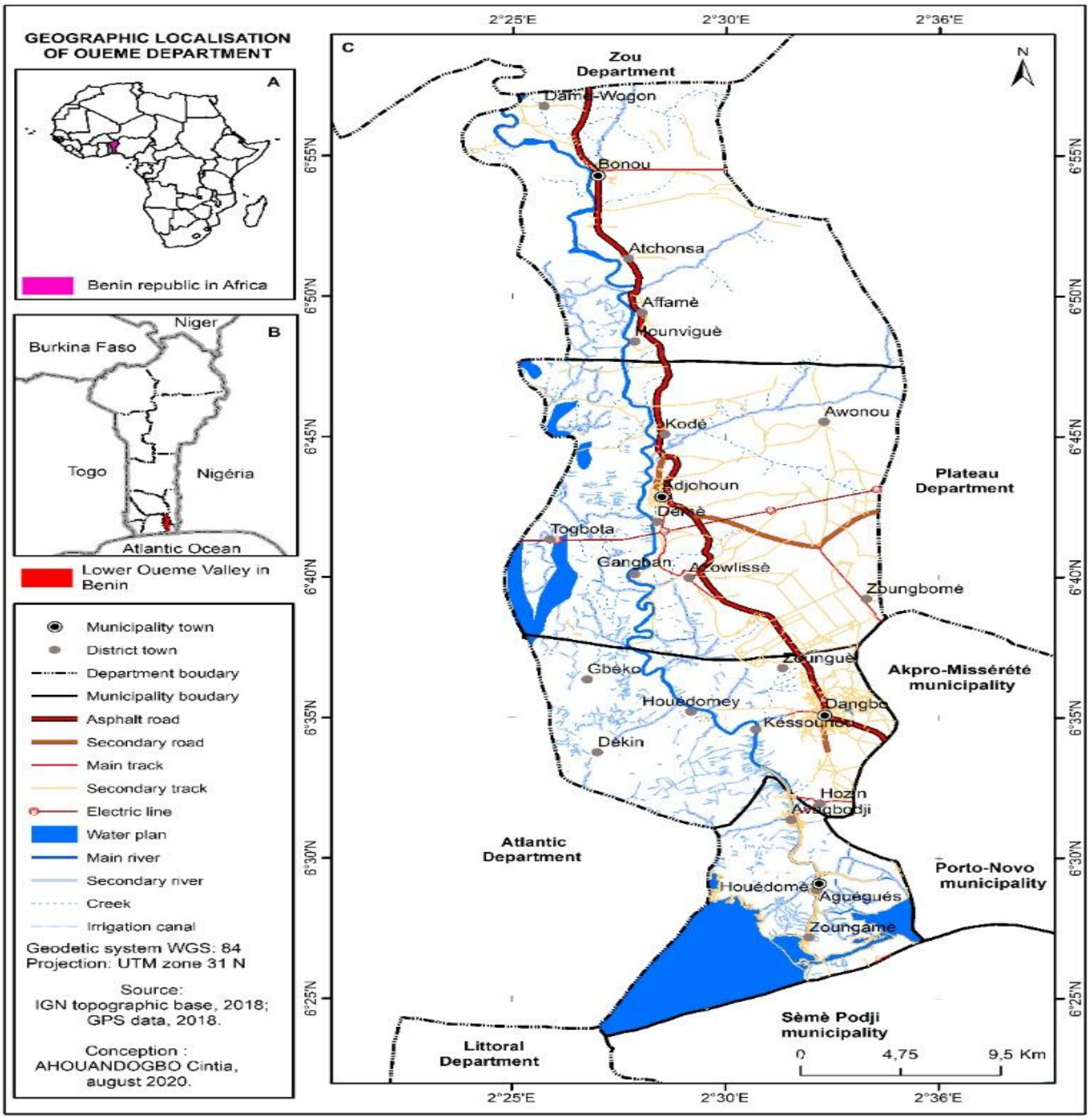

Figure 1: Geographical location of the lower Ouémé valley

III. DATA AND METHODS

2.1. Data

The study of climate requires long and multiple series of observation data. That is why data quality is a major factor (Faye *et al.*, 2019). The data used are about climatological statistics relating to the daily, monthly and annual rainfall from 08 stations whose characteristics are presented in the Table 1 below. These data were collected from the meteorological service of Benin (METEO-Bénin) over a period of 46 years from 1970 to 2016.

Table 1: List of the rainfall/climate stations in the lower Ouémé valley

Name of theStations	Type of Stations	Latitude (°, N)	Longitude (°, E)	Altitude (m)
Abomey	Rainfall	7°18’	1°7’11’’	221
Adjohoun	Rainfall	6°25’00’’	2°13’34’’	79
Bohicon	Synoptic	7°16’	2°4’	260
Bonou	Rainfall	7°33’33’	2°50’00’’	50
Cotonou	Synoptic	6°01’25’’	2°06’53’’	51
Pobè	Agro-climatic	7°33’33’’	3°07’06’’	124

Porto-Novo	Rainfall	6°48’33’’	3°02’06’’	38
Toffo	Rainfall	6°49’	2°3’	37

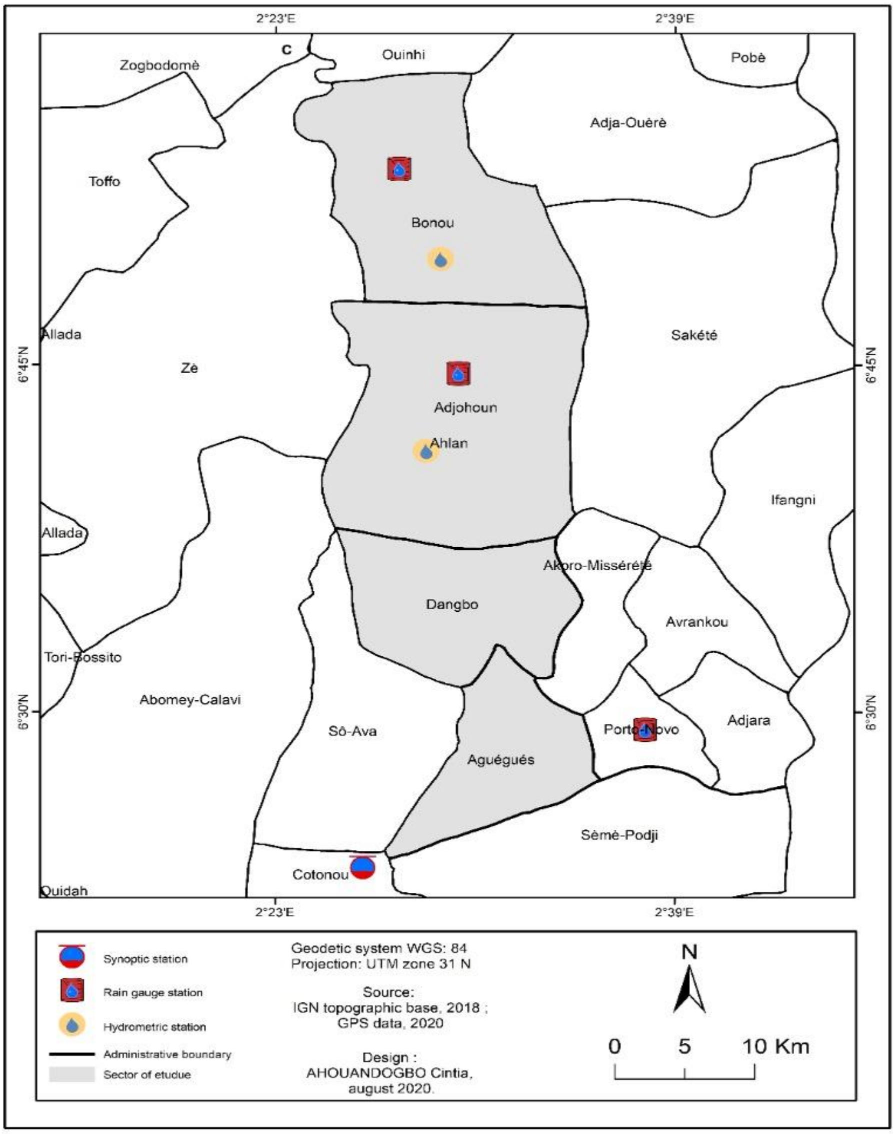

Figure 2: The stations of the lower Ouémé valley

2.2. Methods

2.2.1. Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is based on statistical calculations of precipitation over a long period (at least 30 years). The SPI was developed by (McKee *et al.*, 1993) of Colorado State University, for the determination of rainfall deficits. It is a very important, powerful and easy index to calculate, using precipitations only. Moreover, it has shown to be effective for analyzing both wet and dry periods. It is calculated based on the following equation.

$$SPI = Xi - Xm/Si \quad \text{(Equation 1)}$$

Where, X_i is the cumulative rainfall for year i; X_m and S_i are respectively the average and the standard deviation of rainfalls observed for a given series. This index defines the severity of drought in different classes. The negative annual values indicate a drought compared to the chosen reference period and the positive ones indicate a wet situation.

Table 2: Classification of drought in relation to the value of the Standardized Precipitation Index (SPI) according to (OMM)

SPI Class	Interpretation
SPI >2.0	Extreme wet
1,5 to 1,99	Very wet
1.0 to 1,49	wet
-0,99 to 0,99	Normal
-1.0 to -1,49	Moderate drought
-1,50 to -1,99	Severe drought
SPI < -2.0	Extreme drought

Source:(McKee *et al.*, 1993)

2.2.2. Palmer's Drought Severity Index

Palmer Drought Index also known as the Palmer Drought Severity Index and often abbreviated as PDSI (Palmer Drought Severity Index), is a measure of drought based on recent precipitation and temperature. It was developed by the meteorologist Wayne Palmer, who published his method in 1965 in a drought report for the US National Weather Service's Office of Climatology (Hayes *et al.*, 2007). The Palmer Drought Severity Index is a measure of drought based on recent rainfall and temperature. The index has been shown to be very effective in determining long-term drought that is over several months, but less effective for conditions that last a few weeks (Zargar *et al.*, 2011). We use 0 as the average, and the state of drought is represented by negative values; for example, -2 means moderate drought, -3 means severe drought, and -4 means extreme drought. Palmer's algorithm can therefore be applied for any site as long as precipitation and temperature data are available (Hayes *et al.*, 2007).

It is calculated from the following relation:

$$PDSI = X(i) = 0{,}897X(i-1) + Z(i)/3$$

(Equation 2)

Where X (i-1) is the PDSI of the previous period; Z (i) is the index of the moisture anomaly; i is weeks or months of the year.

$$Z(i) = K(P - Pc) \quad \text{(Equation 3)}$$

Where K is the weight factor (Alley, 1984); P is the current precipitation (mm); Pc is the CAFEC precipitation (mm).

$$Pc = \alpha jPE + \beta jPR + \Upsilon jPRO - \delta jPL$$

(Equation 4)

Where: CAFEC " Climatically Appropriate for Existing Conditions"; α_j, β_j, γ_j, δ_j are weekly or monthly climatic coefficients; j is the week or month of the year; PE is the potential evapotranspiration (mm); PR the potential recharge (mm); PRO the potential runoff (mm) and PL the potential loss in the soil (mm)

Table 3: PDSI classification for dry and wet periods

PDSI Classification for dry and wet period	
4.0 or above	Extremely wet
3.0 to 3.99	very wet
2.0 to 2.99	Moderately wet
1.0 à 1.99	slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.50 to 0.99	Incipient dry spell
-1.0 to 1.99	Slight drought
-2.0 to 2.99	Moderate drought

Source:(Palmer, 1965)

2.2.3. Palmer's Hydrological Drought Index (PHDI)

It is part of the suite of indices developed by Palmer in the 1960s with the United States Weather Bureau. Based on the original PDSI (Palmer Drought Severity Index) and modified to take account longer-term dryness that will affect water storage, stream flow and groundwater. PHDI has the ability to calculate when a drought will end based on the precipitation needed by using a ratio between the humidity received and the humidity required to end a drought (Modarres, 2007). PHDI and PDSI are indicators that measure the difference in moisture supply for the dry as well as the wet phase. They are calculated for weekly or monthly periods in order to characterize regional conditions. It is possible to compare different regions (Medejerab and Henia, 2011). The method of calculating the hydrological Palmer index PHDI is the same as that of the PDSI, by replacing the rainfall data with the discharges.

Table 4: Classification of the PHDI

PHDI	**Classification**
≥4.00	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal

-0.50 to -0.99	Incipient drought
-1.00 to -1.99	Slight drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
≤-4.00	Extreme drought

Source :(Medejerab and Henia, 2011)

IV. Results

4.1. Standardized Precipitation Index (SPI)

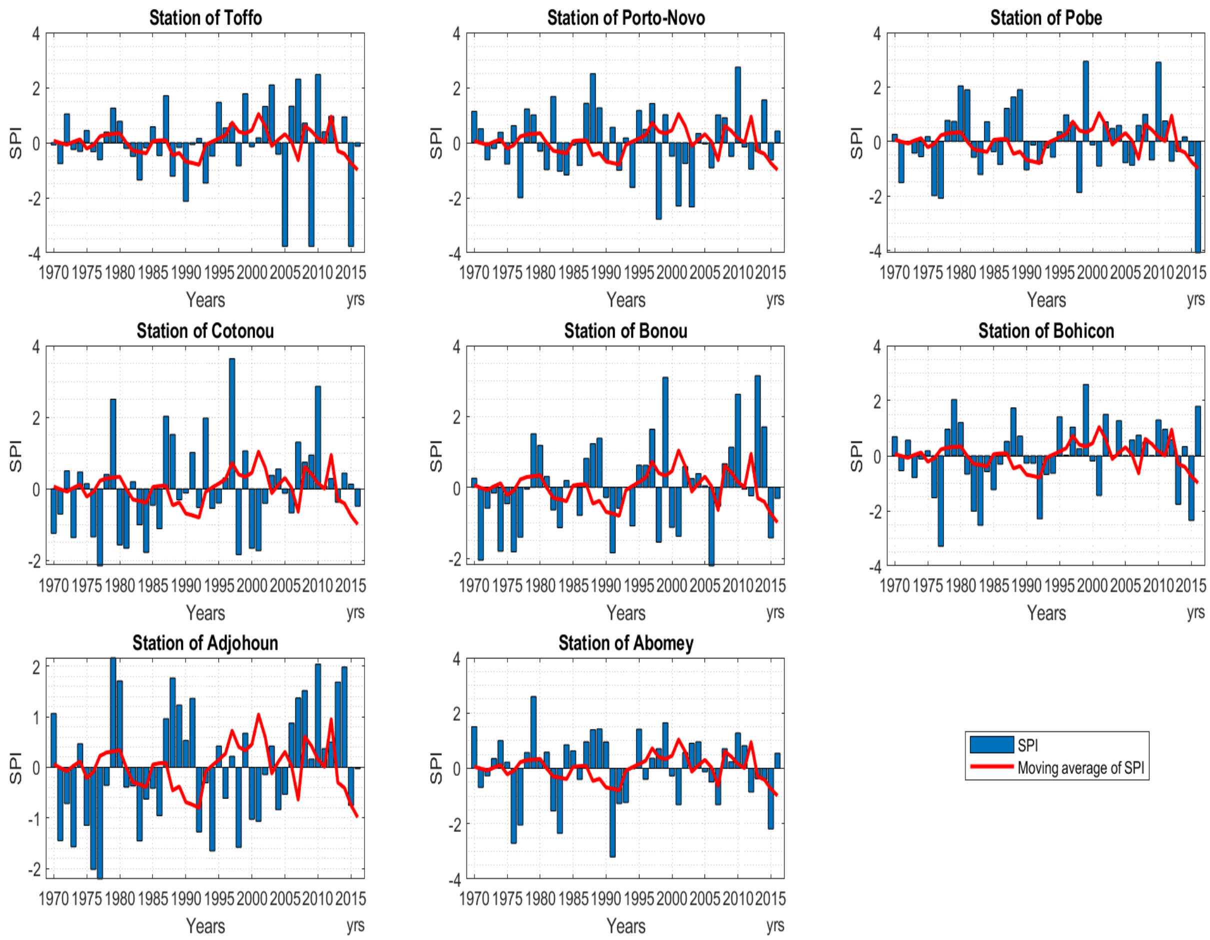

Figure 3: Annual trend of SPI in the 8 stations from 1970 to 2016

Figure 3 shows the annual characteristics of SPI at 8 stations representative of the study area from 1970-2016. By analyzing the moving average at these stations; the period studied can be divided into two sequences: a dry sequence and a wet sequence for the 8 stations. The dry sequence starts from 1972 to 1995 with SPI values between (-0.4 to -2.4); (-0.2 to -1.6); (- 0.4 to -2.2), (-0.2 to -1.6), (-1.2 to -3.4), (-0.9 to -0.3), (-0.2 to -2.2) and (-0.2 to -2.2) respectively for Adjohoun, Bonou, Cotonou, Porto-Novo, Abomey, Bohicon, Pobè and Toffo. The wet period starts from 1995 to 2016 with SPI values between (0.2 to 1.2) at Abomey; (0.4 to 21) at Adjohoun; (0.3 to 2.2) at Bohicon; (0.6 to 3.2) at Bonou; (0.2 to 2.8) at Cotonou; (0.2 to 2.9) at Pobè; (0.4 to 2.8) at Porto-Novo and (0.4 to 2.7) at Toffo.

Table 5: SPI characteristics for the 8 stations in the study area

caracteristic	Abomey		Adjohoun		Bohicon		Bonou	
	Year	Frequency	Year	Frequency	Year	Frequency	Year	Frequency
Extreme wet		0	2010-2015	5	1995-2000	5	1995-2000 2005-2010 2010-2015	15
Very wet		0	1985-1990 2005-2010	10	1975-1980 1985-1990	10		0
wet	1970-1975 19851990 1995-2000	15		0	2000-2005 2005-2010 2010-2015	15	1980-1985 1985-1990	10
Normal	2000-2005 2005-2010	10	1980-1985 1990-1995	10	1970-1975	5		0
Moderate drought	2010-2015	5	1970-1975 1975-1980	10		0		0
Severe drought		0	2000-2005	5		0	1975-1980 1990-1995 2000-2005	15
Extreme drought	1975-1980 1980-1985 1990-1995	15	1995-2000	5	1980-1985 1990-1995	10	1970-1975	5
caracteristic	Cotonou		Pobe		Porto-novo		Toffo	
	Year	Frequency	Year	Frequency	Year	Frequency	Year	Frequency
Extreme wet	1995-2000 2005-2010 2010-2015	15	1975-1980 1995-2000 2005-2010 2010-2015	20		0	2005-2010 2010-2015	11
Very wet	1985-1990 1990-1995	10	1985-1990	5	1985-1990 1995-2000 2005-2010	16	1995-2000	5
wet		0			1970-1975	5	1975-1980	5
Normal		0	2000-2005	5		0	1970-1975	5
Moderate drought	1970-1975	5	1980-1985 1990-1995	10	1980-1985 1990-1995 2010-2015	15		0
Severe drought	1975-1980 1980-1985 2000-2005	15		0	1975-1980	5	1980-1985	5
Extreme drought		0	1970-1975	5	2000-2005	5	1985-1990 1990-1995 2000-2005	15

Legend	
(yellow)	Wet period
(red)	drought periode
(blue)	Empty year

Table 5 above presents the interpretation of the values of the standardized precipitation index (SPI) over the period from 1970 to 2016 for the 8 stations in the study area. The table can be divided into three periods namely: the wet period, the normal period and the dry period. By analyzing the two extremes of the wet period (extremely wet and very wet) we notice that all the stations had extremely wet five-year periods except the Abomey and Porto-Novo stations. The five-year extreme humidity levels common to the stations are: 1995-2000, 2000-2005 and 2005-2010 For the very wet period, all the stations had one or more very wet five-year periods except the Abomey and Bonou stations, these years are: 1985-1990, 1990-1995, 2000-2005 and 2005-2010. Analysis of the two extremes (severely dry and extremely dry) of the dry period reveals that; over the so-called severely dry period, all the stations experienced at least one dry five-year period except the stations of Abomey and Pobè. These five-year terms are: 1975-1980, 1980-1985, 1990-1995 and 2000-2005. For the so-called extremely dry period, we note that all stations have experienced at least one extremely dry five-year period except the Cotonou station. These five years are: 1970-1975, 1975-1980, 1980-1985, 1990-1995 and 1995-2000.

4..2. Palmer's Drought Severity Index (PDSI)

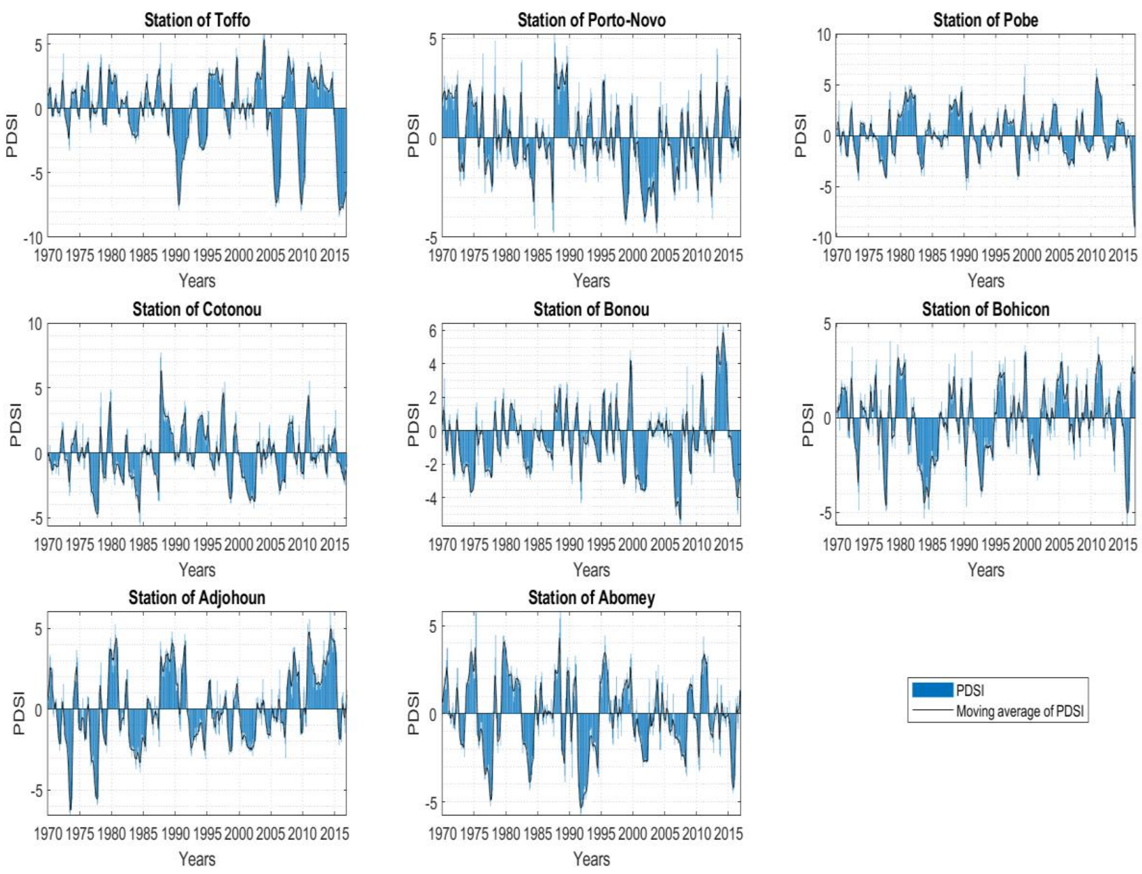

Figure 4: Evolution of the PDSI for the 8 stations from 1970 to 2016

Figure 4 shows the values of the drought severity index, it appears that the PDSI index identified the different periods of drought recorded in the environment over the period from 1970 to 2016. We note a significant fluctuation in dry and wet periods with a strong tendency for wet periods. The study period can be subdivided into two sequences: a dry sequence and a wet sequence. The dry sequence starts from 1970 to 1995 with PDSI values ranging from (-5.9 to -2.2) at Abomey; (-2.9 to - 2.2) at Adjohoun, (-5.9 to -2) at Bohicon; (-4.5 to -1.5) at Bonou; (-5.9 to -2.5) at Cotonou; (- 5.5 to -1) at Pobè; (-5.5 to -1) at Porto-Novo and (-7.9 to -0.6) at Toffo. The wet sequence starts from 1995 to

2016 with PDSI values ranging from (1.9 to 4.5), (1.9 to 6); (1 to 4.4); (1 to 6.5), (1 to 5.5); (1.4 to 6.5); (1 to 4.5) and (0.9 to 7.5) respectively for Abomey, Adjohoun. Bohicon, Bonou, Cotonou, Pobè, Porto-Novo and Toffo.

Table 6: Interpretation of the PDSI values of the 8 stations from 1970 to 2016

caracteristic	Abomey		Adjohoun		Bohicon		Bonou	
	Year	Frequency	Year	Frequency	Year	Frequency	Year	Frequency
Extremely wet	1970-1975 1985-1990 1995-2000	15	1975-1980 1980-1985 1985-1990 2010-2015	20	1975-1980 2010-2015	10	1995-2000 2010-2015	10
very wet	2010-2015	5	2005-2010	5	1970-1975 1985-1990 1995-2000 2005-2010	20	1985-1990	5
Moderately wet	2000-2005	5	1995-2000	5		0		0
slightly wet		0		0		0	2000-2005	5
Incipient wet spell		0		0		0		0
Near normal		0		0		0		0
Incipient dry spell		0		0		0		0
Slight drought		0		0		0		0
Moderate drought		0	2000-2005	5		0	1975-1980 1980-1985	10
Severe drought	1980-1985 2005-2010	10	1990-1995	5	2000-2005	5		0
Extreme drought	1975-1980 1990-1995	10	1970-1975	5	1980-1985 1990-1995	10	1970-1975 1990-1995 2005-2010	15

caracteristic	Cotonou		Pobè		Porto-Novo		Toffo	
	Year	Frequency	Year	Frequency	Year	Frequency	Year	Frequency
Extremely wet	1975-1980 1985-1990 1990-1995 1995-2000 2010-2015	25	1980-1985 1985-1990 1995-2000 2010-2015	20	1985-1990 2010-2015	10	1970-1975 1975-1980 1985-1990 1995-2000 2000-2005 2010-2015	30
very wet			1970-1975 2000-2005	10	1970-1975 1995-2000	10		0
Moderately wet	1970-1975	5		0	1990-1995	5		0
slightly wet		0		0		0		0
Incipient wet spell		0		0		0		0
Near normal		0		0		0		0
Incipient dry spell		0		0		0		0
Slight drought		0		0		0		0
Moderate drought		0		0	1975-1980 2005-2010	10	1980-1985	5
Severe drought	2005-2010	5	2005-2010	5		0		0
Extreme drought	1980-1985 2000-2005	10	1975-1980 1990-1995	10	1980-1985 2000-2005	10	1990-1995 2005-2010	10

Legend	
(yellow)	Wet period
(red)	drought periode
(blue)	Empty year

Table 6 above shows the interpretation of the Palmer Drought Severity Index (PDSI) values over the period 1970 to 2016 for the 8 stations in the study area. The characteristics can be divided into three periods: the wet period, the normal period and the dry period. In our analysis we will focus on the wet and dry period. The wet period includes: the extremely humid and very humid period. In the study environment all the stations experienced an extremely wet five-year period. These common five-year terms are: 1970-1975, 1975-1980, 1980-1985, 1995-2000, 2000-2005 and 2010 -2015. The very wet period is present in all the stations except the Cotonou and Toffo stations. The years of humidity are: 1970-1975, 1985-1990, 2000-2005 and 2005-2010. The dry period is characterized by: extreme drought and severe drought. The extreme drought is manifested at all the stations, we have the following five-year periods: 1975-1980, 1980-1985, 1990-1995 and 2000-2005. The severe drought is evident in all the stations except those of Bonou, Porto-Novo and Toffo. The years of severe drought for the other stations are: 1980-1985, 1985-1990 and 2005-2010.

4.3. Palmer's Hydrological Drought Index (PHDI)

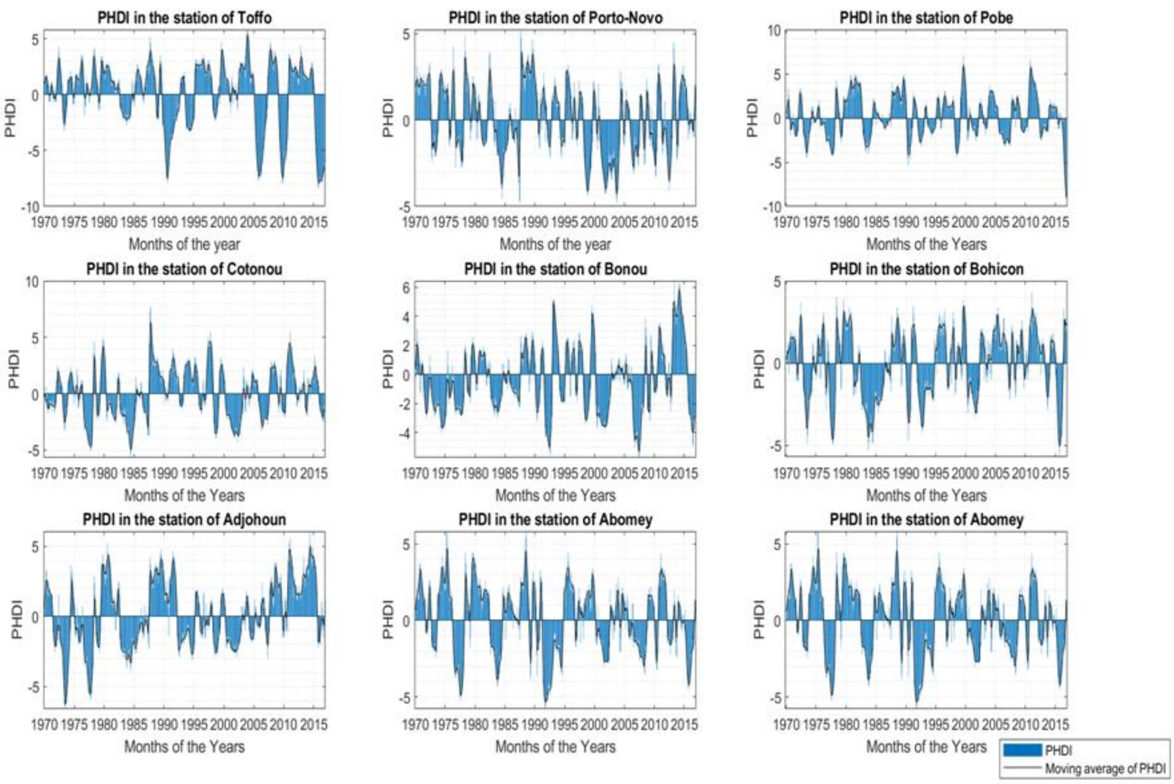

Figure 5: Evolution of the PHDI in the 8 stations from 1970 to 2016

Figure 5 shows the values of the hydrological index of palmer, it appears that the PHDI index made it possible to identify the different periods of hydrological drought recorded in the environment over the period from 1970 to 2016. We note a significant fluctuation of the levels. Dry and wet periods with a strong tendency for wet periods. The study period consists of a wet sequence with some dry periods in the series. PHDI values vary between (0.5-5.9) at Abomey, (0.5-6) at Adjohoun; (0.5-4.6) at Bohicon; (0.5-6.5) at Bonou; (0.5-7.8) at Cotonou; (0.5-7.1) at Pobè; (0.5-4.5) at Porto-Novo and (0.5-5.9) at Toffo.

Table 7: Interpretation of the 1970-2016 PHDI values for the 8 stations

	Abomey		Adjohoun		Bohicon		Bonou	
caracteristic	Year	Frequency	Year	Frequency	Year	Frequency	Year	Frequency
		0		0		0		0
Extremely wet		0		0		0		0
Very wet	1970-1975 1975-1980 1985-1990 1995-2000	20	2010-2015	5		0	2010-2015	5
Moderately wet	1980-1985 2010-2015	10	1980-1985 1985-1990 2005-2010	15	1970-1975 1975-1980 1995-2000 2005-2010 2010-2015	25		0
Slightly wet	2000-2005	5	1970-1975 1995-2000	10	1985-1990	5	1985-1990 1995-2000	10
Incipient wet spell		0		0		0		0
Near normal		0		0		0		0
Incipient drought		0		0		0		0
Slight drought	2005-2010	5	1990-1995 2000-2005	10	1980-1985 2000-2005	10	1975-1980	5
Moderate drought		0		0		0	1970-1975 1980-1985 2000-2005	15
Severe drought	1990-1995	5		0	1990-1995	5	1990-1995 2005-2010	10
Extreme drought		0	1975-1980	5		0		0
caracteristic	Cotonou		Pobè		Porto-Novo		Toffo	
	Year	Frequency	Year	Frequency	Year	Frequency	Year	Frequency
Extremely wet		0	1995-2000 2010-2015	10		0		0
Very wet	1990-1995 1995-2000 2010-2015	15		0	1985-1990	5	1985-1990 2000-2005 2010-2015	15
Moderately wet		0	1970-1975 1985-1990 2000-2005 2005-2010	20	1970-1975 1970-1975 1995-2000 2010-2015	20	1970-1975 1975-1980 1995-2000	15
Slightly wet		0		0		0	1980-1985	5
Incipient wet spell	1985-1990	5		0		0		0
Near normal		0		0		0		0
Incipient drought		0		0		0		0
Slight drought		0		0	1990-1995	5		0
Moderate drought	1970-1975 2000-2005 2005-2010	15	1975-1980	5	1980-1985 2005-2010	10		0
Severe drought	1975-1980 1980-1985	10	1980-1985 1990-1995	10	2000-2005	5		0
Extreme drought		0		0		0	1990-1995 2005-2010	10

Legend	
(yellow)	Wet period
(red)	drought periode
(blue)	Empty year

Table 7 above shows the values of the Palmer Hydrological Drought Index (PHDI) over the period 1970 to 2016. The table is divided into three periods: a wet period, a normal period and a dry period. We will focus our analysis on wet and dry years, because we want to deal with climatic extremes. The wet period we have the extremely humid and very humid. We note that for the extremely wet period none of the stations experienced this extreme except the Pobè station (1995-2000 and 2005-2010). In terms of the very wet period, all the stations experienced a wet five-year period except the Bohicon and Pobè stations. These five years are: 1975-1980, 1980-1985, 1985-1990, 2000-2005 and 2005-2010. The dry period is characterized by: severe drought and extreme drought. Severe drought is evident at all stations except Adjohoun and Toffo. The severely dry five-year terms are: 1980-1985, 1990-1995 and 2000-2005. The extreme drought is evident in all the stations except: Abomey, Bohicon, Bonou, Cotonou, Pobè and Porto-Novo. These extremely dry years are: 1975-1080, 1990-1995 and 2005-2010.

V. DISCUSSION

The analysis of hydro-climatic variability in the lower Ouémé valley using the SPI, PDSI and PHDI drought indices allowed us to analyze the trend of wet and dry years. The general trend across the three indices reveals that the study period is divided into two sequences: a dry sequence and a wet sequence. The observed precipitation deficit for the SPI covers the period from 1970 to 1995 and the wet period from 1995 to 2016. The agricultural drought assessed using the PDSI covers the period from 1970 to 1995 for years of lack of moisture in soil and 1995 to 2016 for wet years. The measurement of the deficit of surface and groundwater was assessed using the PHDI hydrological drought index. Over the study period we note that wet years are very dominant with hydrological droughts dispersed in the data series. SPI, PDSI and PHDI agree on the same periods of drought and humidity. Indeed we observe a great period of drought from the 70s at the level of the SPI and the PDSI, which agree on these five-year periods: 1975-1980, 1980-1985, 1985-1990, 1990-1995, 2000-2005 and 2005-2010. These years are characterized by severe droughts and extreme droughts. These results confirm those of (Mahe *et al.*, 2001) in West and Central Africa, (Mahe *et al.*, 2011) in Niger, (Soro *et al.*, 2014) in Côte d'Ivoire (Bigot *et al.*, 2005) in Côte d'Ivoire and (Faye, 2018) in Senegal. With regard to wet periods, the three indices agree on certain five-year periods, namely: 1985-1990, 1995-2000, 2000-2005 and 2005-2010. These years are characterized by very humid periods and extremely humid periods. These results corroborate those of several authors such as: (Faye *et al.*, 2015) in Senegal, (Mahaman Bachir and Savane, 2009) in Ivory Coast, (Soro *et al.*, 2014) in Ivory Coast. The 8 stations studied are evenly distributed on and around our study environment. If we focus our analysis on a few towns in the lower Ouémé valley, which are: Adjouhoun, Bonou and Aguégués. The analysis of the SPI, PDSI and the PHDI reveals the same trends at the level of the three municipalities. That is to say that after 1970 we have a significant rainfall deficit which is characterized with peaks around the 1975-1980, 1980-1985, 1990-1995, 2000-2005 and 2005-2010 five-year periods. These peaks were characterized by droughts of the extremely severe and severely dry type. These results are consistent with those of several other authors who have worked in the lower valleys of the Ouémé such as:(Kodja, 2018) , (Vissin *et al.*, 2016),(Olivier *et al.*, 2018). The hydro-agricultural developments in our study environment have suffered the impacts of droughts and floods during these years. Periods of drought led to less water in the fields, the retreat of the stream making it more expensive to pump water for irrigation, decrease in water in fish ponds, loss of water crops by lack of water. During periods of flooding, the basic developments are completely destroyed by the water, which leads to the repair of dikes, bunds and canals after the floods. It should also be noted the loss of fish from fish ponds and the loss of crops. The same contacts were made by (Ibouraïma, 2006), (Abou *et al.*, 2018).

VI. CONCLUSION

The analysis of the variability of hydro-climatic risks was made with the standardized precipitation index (SPI), the drought severity index (PDSI) and the hydrological drought index (PHDI) in the lower valley of Ouémé. The three indices allowed to describe droughts periods and the high humidity periods in the lower valley between 1970 and 2016. The results indicate significant climatic variability in the lower Ouémé valley with a relatively better frequency of occurrences wet. The values of SPI, PDSI, and PHDI indicate years of drought from 1970 to 1995 and years of high humidity from 1995 to 2016 at all stations. The indicators of the three indices show a heterogeneous distribution of precipitation across the lower valley for both dry and wet periods. The three indices agree on these five-year drought: 1975-1980, 1980-1985, 1985-1990, 1990-1995, 2000-2005 and 2005-2010. These years are characterized by severe droughts and extreme droughts. Likewise, they agree on the wet sequence years which are: 1985-1990, 1995-2000, 2000-2005 and 2005-2010. These years are characterized by very humid periods and extremely humid periods. These results can be used to predict droughts in the lower Ouémé valley watersheds that allow the effective planning and management of water resources and agricultural activities, as well as the development of drought adaptation measures.

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