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Characterization of Meteorological Drought in the Alibori Watershed (North Benin, West Africa)

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Abstract: Benin has experienced a significant variation in rainfall with prolonged drought since 1970. In view of the consequences of this extreme phenomenon on vital sectors, such as agriculture, updating the results previously obtained is obviously essential to guarantee optimal management of water resources. The present study aims to characterize the drought in the Alibori watershed in northern Benin. The climatic data used are those made available by the National Aeronautics and Space Administration (NASA) through its POWER "Prediction of Worldwide Energy Resources"; they cover the period from 1981 to 2018. Four approaches were used to assess drought in the basin: the Standardized Precipitation Index, the Climatic Moisture Index, the segmentation of Hubert and Spearman's correlation. The analysis of the precipitation data shows decreasing trends in the lower part of the basin and increasing trends in the middle and upper part. Over the period from 1981 to 2018, we note that the frequency of moderate and severe droughts varies respectively between 31.8% to 39.47% and 15.79% to 18.42%. Extreme drought was observed in 2000 west of the middle part of the Alibori watershed around the point of Latitude 11.0645 and Longitude 2.2944. The data used clearly highlights drought situations in the Alibori watershed.

Keywords: Drought, Alibori, Characterization, POWER

1. Introduction

Like other West African countries, Benin has been the scene of extreme climatic events since the 1970s, as evidenced by the work of several authors such as [1-5].

More specifically, the northern part of the country suffers the greatest rainfall deficit with a generalization of drought and a constant decrease in the number of rainy days since 1958, 1977 and 1983 [6].

These climatic disturbances have impacts on vital sectors such as agriculture. Among other consequences, we have agricultural production conditions that are increasingly difficult [7]; livestock and crop systems that are less productive [8]; lower incomes and a weakening of food security [9-11]. Moreover, the mastery of climatic information is obviously essential to contain these hazards. In this context, continuous updating of results is fundamental.

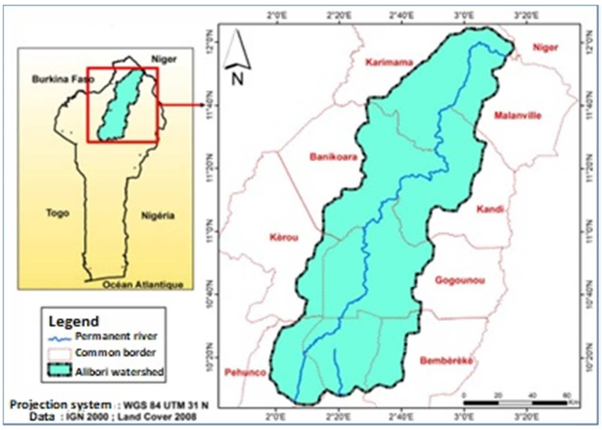

Figure 1. Location of the Alibori watershed.

The present study aims to characterise the meteorological drought in the Alibori watershed using climate data made available by the National Aeronautics and Space Administration (NASA).

The study basin is located in the northern region of Benin between 10°0' and 12°5' North Latitude and 1°95' and 3°15' East Longitude. It covers an area of about 13888.02 km^2 and belongs to the Niger river basin (Figure 1).

2. Materials and Methods

2.1. Material

The climatic data used are those made available by NASA through its POWER "Prediction of Worldwide Energy Resources". These data include daily precipitation, maximum and minimum temperatures, relative humidity, wind speed and insolation. They cover the period from 1981 to 2018 and have the advantage that there are no gaps, except for insolation, which is not available from 1981 to the 181st day of 1983. The data extraction points constitute the centres of the 24km×24km quadrants (i.e. 576 km^2) carried out in the study area (Figure 2) because according to Abou Amani, 2005 cited by [12], the World Meteorological Organisation (WMO) recommends one rain gauge for an area of 572 km^2 in the interior plains. In total, eleven (11) different sets of data are obtained over the entire catchment area (Figure 2).

The catchment area comprises three main parts: Upper Alibori, Middle Alibori and Lower Alibori.

S1 and S2 characterise the western and eastern parts of the Upper Alibori respectively.

S3 and S4 characterise the south-western and south-eastern parts of the Middle Alibori respectively.

S5 characterises the western part of the Middle Alibori.

S6 characterises the central part of the Middle Alibori.

S7 covers the eastern part of the Middle Alibori.

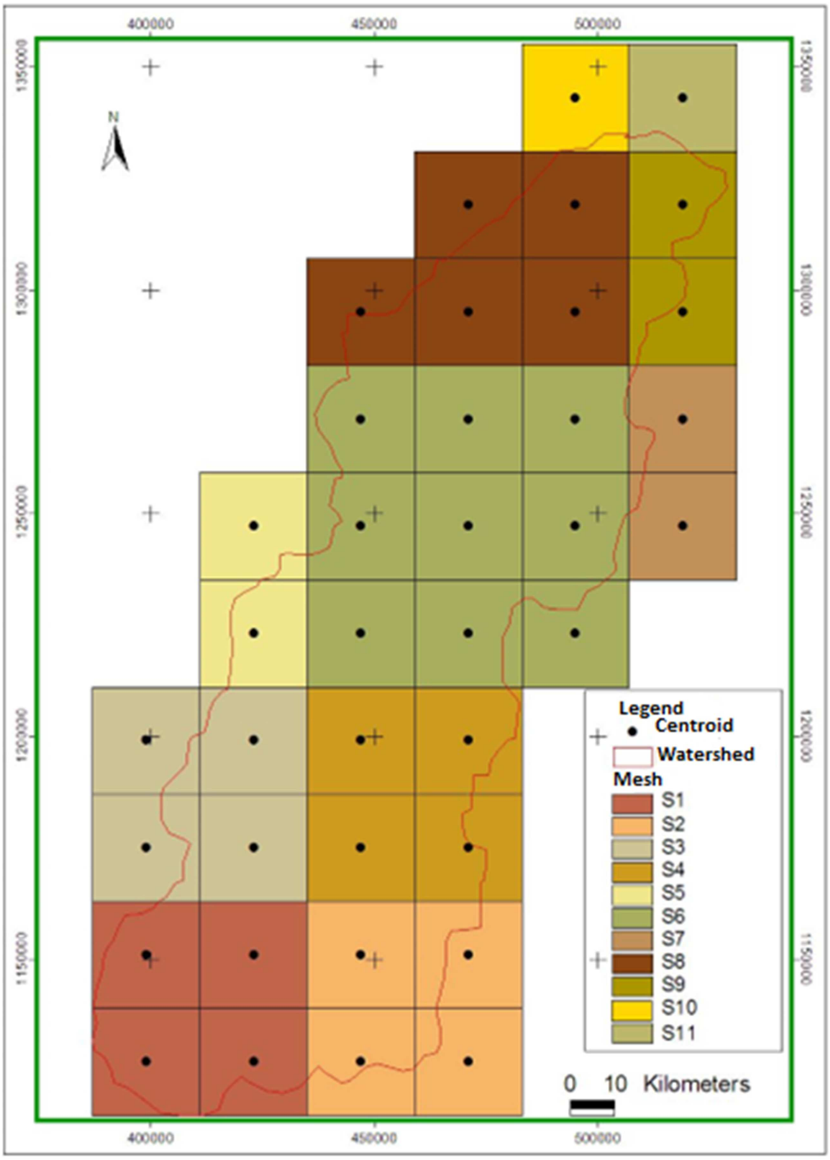

Figure 2. *Grid of the study area and location of data extraction points.*

2.2. Methods

Four approaches were used to assess drought in the basin: the Standardised Precipitation Index (SPI), the Climatic Moisture Index (CMI), Hubert segmentation and Spearman rank correlation.

The SPI was developed by Mckee T. B. and *al.* [13] and is defined by (1):

$$SPI = \frac{Xi - Xm}{Si} \quad (1)$$

where Xi is the cumulative rainfall for a year i; Xm and Si, are respectively the mean and standard deviation of the annual rainfall observed for a given series. The drought classes according to the SPI values are given in Table 1.

Table 1. *Classification of drought in relation to the value of the Standardised Precipitation Index (SPI).*

SPI class	Degree of drought
SPI>2	Extreme humidity
1<SPI<2	High humidity
0<SPI<1	Moderate humidity
-1<SPI<0	Moderate drought
-2<SPI< -1	Strong drought
SPI < -2	Extreme drought

In 2009, the WMO recommended that the SPI be used primarily to monitor changes in meteorological drought conditions [14].

The SPI has already been used by several authors as [15] (in China); [16, 19] (in Senegal) and [8] (in Benin).

The CMI provides an overview of water stress and is strictly defined by (2):

$$CMI = \frac{P}{ETP} - 1 \text{ if } P < ETP$$

Or

$$CMI = 1 - \frac{ETP}{P} \quad (2)$$

Otherwise

CMI is ranges from -1 to 1.

The drought classes in relation to the CMI are shown in Table 2.

Table 2. *Drought classification in relation to the value of the Climatic Moisture Index (CMI).*

CMI class	Degree of drought
CMI > 0	Moist zone
-0,6 <CMI<0	Semi-arid zone
CMI<-0,6	Arid zone

The CMI has been used by several researchers such as [17-19].

Potential evapotranspiration was calculated using the PENMAN-MONTEITH-FAO method. This method is considered to be the best adapted to the African tropical zone [20-22].

In addition, the rainfall data series were subjected to the HUBERT segmentation test, which can be considered as a stationarity test [23] and then to the rank correlation test, which checks the randomness of the series [24].

3. Results

3.1. Rainfall Trends

The analysis of rainfall trends shows that the S1, S2, S3, S4, S5, S6 and S7 series, representative of the upper and middle parts of the catchment area, show an increasing trend, while the S8, S9, S10 and S11 series, representative of the lower part of the study area, show a decreasing trend.

Figures 3 and 4 show the evolution of annual rainfall in the S1 and S8 series of the Alibori watershed.

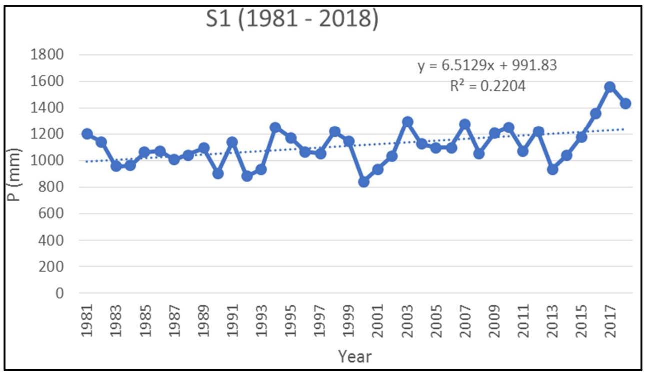

Figure 3. *Evolution of annual rainfall and trend over the S1 series.*

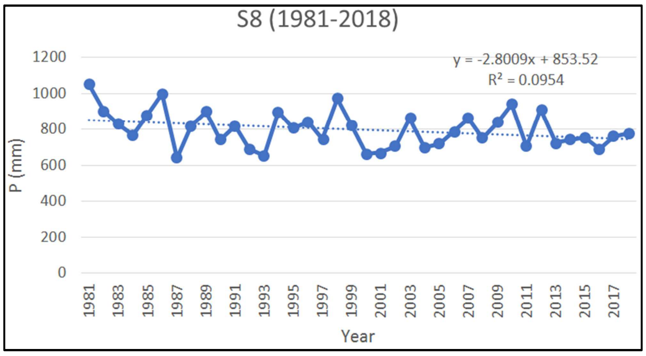

Figure 4. *Evolution of annual rainfall and trend over the S8 series.*

3.2. Degree of Drought by Standardised Precipitation Index

The Table 3 shows the frequency of years by SPI class for each series.

The analysis of this table shows that over the entire catchment area and over the period under consideration, dry conditions are greater than wet conditions. This observation is the same for all series except for the S3, S7 and S10 series where the frequency of dry years is equal to that of wet years.

Furthermore, all drought classes according to the SPI are found in the catchment area. The frequency of moderate and severe droughts varies between 31.8% and 39.47% and 15.79% and 18.42% respectively. Only one extreme drought was observed (in 2000), precisely in the western part of the middle part of the Alibori Basin, around the point of Latitude 11.0645 and Longitude 2.2944, in the commune of Banikoara. It can therefore be noted that over the study period and over the whole watershed, moderate drought is quite important and extreme drought is rare.

Table 3. *Frequency of years by Standardised Precipitation Index (SPI) classes over the period 1981 to 2018.*

Series	Extreme Drought	Severe drought	Moderate drought	Total Drought	Moderate humidity	High humidity	Extreme Humidity	Total Humidity
S1	0,00	18,42	36,84	55,26	31,58	7,90	5,26	44,74
S2	0,00	18,42	39,47	57,89	28,95	7,90	5,26	42,11
S3	0,00	18,42	31,58	50,00	36,84	7,90	5,26	50,00
S4	0,00	18,42	36,84	55,26	31,58	7,90	5,26	44,74
S5	2,63	15,79	34,21	52,63	26,32	21,05	0,00	47,37
S6	0,00	15,79	36,84	52,63	26,32	18,42	2,63	47,37
S7	0,00	18,42	31,58	50,00	23,68	26,32	0,00	50,00
S8	0,00	15,79	36,84	52,63	28,95	15,79	2,63	47,37
S9	0,00	15,79	36,84	52,63	26,32	15,79	5,26	47,37
S10	0,00	18,42	31,58	50,00	34,21	10,53	5,26	50,00
S11	0,00	15,79	36,84	52,63	28,95	15,79	2,63	47,37

3.3. Climatic Moisture Index (CMI)

After analysis of the CMI values, no value greater than 0 (characteristic of humid conditions) was observed in the catchment area. The negative values obtained reveal the existence of both semi-arid and arid conditions in the catchment. Table 4 shows the percentage of years by drought degree class according to the CMI.

Table 4. *Percentage of years per CMI class.*

Series	Moist	Semi-arid	Arid
S1	0	100	0
S2	0	100	0
S3	0	97	3
S4	0	92	8
S5	0	71	29
S6	0	58	42
S7	0	55	45
S8	0	26	74
S9	0	29	71
S10	0	5	95
S11	0	5	95

From the analysis of this table, it emerges that in the S1 and S2 series (representing the Upper Alibori) 100% of the years of observation reveal a semi-arid condition. In the S3 and S4 series (representing the southern part of the middle Alibori) only the years 2000 (for S3) and 1992, 1993 and 2000 (for S4) show an arid condition. The percentage of years showing arid conditions becomes more and more important (up to 95%) as one moves towards the lower part of the catchment.

3.4. Hubert Segmentation and Spearman Rank Correlation

Table 5 gives the results of the HUBERT segmentation for the eleven representative series of the whole catchment area.

The analysis of this table shows that seven series (S1, S2, S3, S4, S8, S9, S11) out of eleven are affected by a break while the other series are homogeneous. Furthermore, the break in the series representing the upper part of the catchment (S1, S2, S3 and S4) occurred between 2014 and 2016, while the break in the series representing the lower parts of the catchment (S8, S9 and S11) occurred in 1986. A comparison of the average rainfall before and after the rupture shows an increase in rainfall after the rupture in the upper part of the catchment and a decrease in the lower part.

Table 5. *Hubert segmentation result (values in mm) over the period 1981 – 2018.*

	Time period	Year of break-up	Number of break-ups	Average before	Average after
S1	1981 – 2018	2015	1	1089,711	1458,633
S2	1981 – 2018	2016	1	1057,542	1476,400
S3	1981 – 2018	2014	1	1008,553	1296,250
S4	1981 – 2018	2016	1	990,981	1400,100
S5	1981 – 2018	Homogeneous series	0		
S6	1981 – 2018	Homogeneous series	0		
S7	1981 – 2018	Homogeneous series	0		
S8	1981 – 2018	1986	1	904,967	779,009
S9	1981 – 2018	1986	1	906,000	774,047
S10	1981 – 2018	Homogeneous series	0		
S11	1981 – 2018	1986	1	812,567	704,231

Table 6 gives the results of the rank correlation test applied to the eleven series of the Alibori watershed.

The null hypothesis of no change is rejected for series S1, S3, S4 and S9 at the 95% and 90% confidence levels. On the other hand, it is accepted for all the series at the 99% confidence level, although most of them show a break at the 1% significance level of the SCHEFFÉ test. This acceptance shows the persistence of the drought in the catchment area.

Table 6. *Results of the rank correlation test between the pre- and post-break sub-periods according to Hubert's segmentation applied to the period 1981-2018.*

Series	99% confidence level	95% confidence level	90% confidence level	Value of variable	Date of rupture at the 1% level of the Scheffe test
S1	Accepted	Rejected	Rejected	2,4767	2015
S2	Accepted	Accepted	Rejected	1,8229	2016
S3	Accepted	Rejected	Rejected	2,5270	2014
S4	Accepted	Rejected	Rejected	1,9989	2016
S5	Accepted	Accepted	Accepted	1,0183	
S6	Accepted	Accepted	Accepted	0,4400	
S7	Accepted	Accepted	Accepted	0,0880	
S8	Accepted	Accepted	Accepted	-1,3703	1986
S9	Accepted	Rejected	Rejected	-2,1498	1986
S10	Accepted	Accepted	Accepted	-1,2446	
S11	Accepted	Accepted	Rejected	-1,7224	1986

4. Discussion

The decreasing rainfall trend observed in the present study is consistent with the results obtained by several studies, in West Africa in general [25, 26], particularly in Benin [2, 4] and more specifically in the northern Benin [6]. The rainfall increase observed in the upper and middle part of the catchment area confirms the results obtained by [27, 28] with data comming from the Agency for Air Navigation Safety in Africa and Madagascar.

Furthermore, the existence and persistence of drought conditions corroborate the findings of [29]. The fairly high proportions of moderate and rare extreme drought obtained in the present study are similar to those obtained by [8] at the Bembereke station located in the same region as our study area.

5. Conclusion

The present study characterises the meteorological drought in the Alibori catchment using climate data made available by NASA through its POWER. The evolution of annual rainfall shows an increasing trend in the upper and middle part of the watershed and a decreasing trend in the lower part (located further north in Benin) of the Alibori watershed. The application of the CMI does not reveal any moisture conditions in the catchment. The Standardized Precipitation Index reveals drought conditions higher than moisture conditions. Moderate drought is the most important over the whole catchment and extreme drought is only observed in 2000 and in one series. The results obtained with the data used are consistent with previous results and the current situation in the study area. It is therefore conceivable that the NASA POWER data could be used in the implementation of agricultural projects in locations without observation data.

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