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Study of extreme hydroclimatic events in the Beninese basin of the pendjari in Porga (West Africa)

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Abstract

Knowledge of hydroclimatic risks constitutes a major challenge for African States, specifically those of West Africa which are highly sensitive to extreme situations (floods, droughts). The objective of this work is to study the extreme hydroclimatic events their manifestations in the Beninese basin of Pendjari in Porga.

The methodological approach adopted required the use of climatological (amount of daily and monthly rainfall) and hydrometric (flow) data from 1965 to 2017 were collected. The data were then processed using descriptive statistics methods.

The analysis of the results shows that the Beninese basin of Pendjari recorded 0.95% years with extreme humidity, 6.60% years with high humidity, 36.80% for years with moderate humidity, 40, 57% of years with moderate drought, 13.21% of years with severe drought and 1.89% of years with extreme drought. In addition, the floods observed in the Beninese basin of Pendjari in Porga are average floods which caused flooding especially during the years 1968, 1969, 1998, 2002, 2008 and 2010 which correspond to periods of extreme and high humidity. The consequences of these climatic disturbances are already perceptible in the environment and constitute hazards that hamper socio-economic development. Floods and pockets of drought impact subsistence farming,Faced with such a situation, the implementation of appropriate and effective strategies must be taken to reduce the vulnerability of the populations.

***Keywords:* Beninese basin of the Pendjari in Porga, extreme hydroclimatic events, rainfall deficits, vulnerability**

1. Introduction

Climate change, a new threat which nowadays leads to increased frequency and intensity of floods, droughts and cyclones, to sea level rise, adds an additional burden to a situation. already very worrying in rural areas. These natural disasters result in a significant drop in harvests, water shortages and a worsening of health crises, with the consequences of growing food insecurity among the populations, thus threatening the progress made in the fight against poverty (B. Diouf and al., 2014, p. 15). According to A. Hamdane (2015, p. 6), the great droughts of the last century (1937-38, 1947-48) are still remembered: they caused major famines. These prolonged episodes of drought are a reminder that Tunisia is a semi-arid and arid country with fundamentally insufficient water resources. The socioeconomic damage caused by droughts remains extremely high, particularly in agriculture.

Moreover, the Sahel and West Africa are, according to the IPCC (2007, p. 5), among the region most vulnerable to future climatic fluctuations. The Sahel must also count with strong demographic growth (3% on average per year), which contributes to a strong and continuous degradation of natural resources, thus aggravating poverty and food insecurity. Demographic forecasts agree on a population of 100 million people by 2025, with half of this population in cities (UNEP, 2011, p. 4).

A. Gaye, taken up by O. Koudamiloro, (2017, p. 22), underlines that an exponential increase in the number of floods following heavy rains has been observed. According to the same author, the number of these events fell on average from less than two per year before the 1990s to more than eight or even twelve per year during the 2000s in West Africa. From Dakar via Bamako, Niamey to Cotonou on the coast of the Gulf of Guinea, floods have been very recurrent in recent decades.

This situation is likely to continue with the climate changes affecting Africa in general and West Africa in particular. Indeed, West Africa has been confronted for more than thirty (30) years with a phenomenon of hydro-pluviometric variability which is reflected, among other things, by the decrease in rainfall accumulations and the flow of major rivers. water (M. Sylla, 2017, p. 23). Thus the vulnerability of agriculture to climate change is felt everywhere. And, this is why the issue of rainfall variability has become a major concern, insofar as its impact is detrimental to human development (GY Kimba, 2011, p. 10).

The Beninese watershed of Pendjari (figure 1) is one of the four (04) large watersheds of the Republic of Benin. It is located in the department of Atacora and located between 10 ° 14 'and 11 ° 30' north latitude and 0 ° 48 'and 2 ° 05' east longitude (EM Idieti, 2012, p. 14).

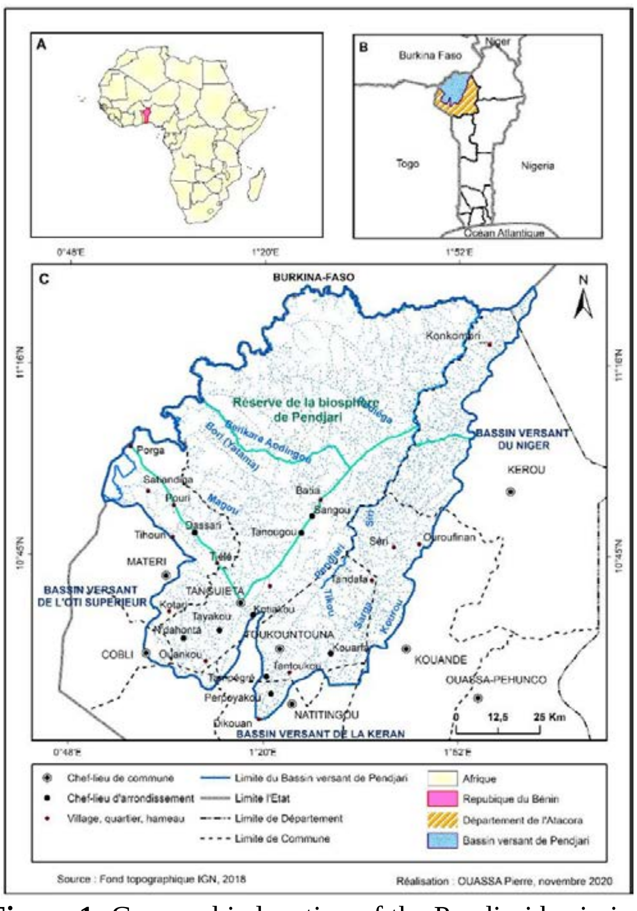

Figure 1: Geographic location of the Pendjari basin in Benin

2. Data and methods

2.2 Data used

Several types of data are used in this study. These include:

✓ climatological statistics: rainfall (daily, monthly and annual) over the period 1965-2017 and potential evapotranspiration (1965-2017). The maximum and minimum temperatures (monthly) of the synoptic station of Natitingou were collected at Météo-Bénin;
✓ hydrometric statistics (daily and monthly flows) in Porga over the period 1965-2017) which were taken from the database of the Hydrology Service of the General Directorate of Water in Cotonou;
✓ agricultural data (areas sown, agricultural production and yields per crop) collected at the Territorial Agency for Agricultural Development of the department of Atacora;
✓ qualitative information from socio-anthropological investigations of the study environment.
All the data thus obtained was processed using the appropriate methods.

2.3 Methods used

The sample size for the field surveys was determined in a reasoned manner based on the following criteria: to be a producer and to have lived permanently in the environment for the last thirty years, to be a technician in the agricultural production sector or in charge of " any farmer organization (PO) involved in the research environment. A total of 126 people including 105 agricultural producers and 21 resource people were surveyed in 21 villages as part of this study. The methods used within the framework of this work are essentially statistical. They result in particular from the reconstruction of statistical series and the analysis of hydroclimatic data.

2.3.1 Reconstruction of the series of maximum and minimum annual heights of hydroclimatic parameters

The inventory of rainfall data revealed gaps in observations. In order to have continuous series and long durations, we proceeded to fill in the series of observations. Indeed, there are several ways to estimate at a given moment the probable value of a parameter which has not been observed. The choice of the reconstitution method depends on the duration of the gap, its position on the annual hydrograph, the information available (existence of neighboring stations, physical characteristics of the watershed, rainfall data), the time step concerned and the objectives pursued by the planned study (M. Assaba, 2014, p. 67).
The various data files have been verified. With the exception of the synoptic station data, all other series show gaps at varying rates. These missing data were reconstructed by the least squares method. This method is based on the multiple regression calculation between the lacunar series and the complete series of stations or stations located in a similar and close geographical environment. The method consists in considering as the first explanatory variable the one whose correlation coefficient with the variable to be explained is the highest (M. Assaba, 2014, p. 67). It consists in introducing each time the variable which increases the value of the correlation coefficient (R) the most in order to obtain a high variance R2 for a minimum of explanatory variables.

2.3.2 Method of drought analysis

Droughts can be quantified using several indices. In this study the standardized precipitation index (McKee et al., 1993) were used. In fact, the analysis of drought comes down to taking into consideration its duration as well as its severity, intensity and spatial extension (A. Agrhab, 2003, p. 12).

➢ **Standardized precipitation index (SPI)**

The Standardized Precipitation Index (SPI) can characterize the precipitation deficits for a given period. It is based, on the one hand, on the definition of a threshold to decide on the state of drought or not by declaring the period, object of the study, dry or not and, on the other hand, it presupposes the identification of the normal or average year. At the end of this operation, it is possible to determine the number of years per SPI range and the corresponding meaning in terms of the magnitude of the climatic phenomenon (Table I) from the following equation: SPI = (pi - pm) / σ

Pi is the Precipitation of year i, Pm the mean Precipitation and σ the Standard Deviation or standard deviation.

Table I: Classification of the drought index in relation to the value of the Standardized Precipitation Index (SPI).

Categories	**SPI values**
Extreme humidity	> = 2
Severe humidity	1.5 to 1.99
Moderate humidity	1 to 1.49
Light humidity	0 to 0.99
Mild drought	-0.990 to 0
Moderate drought	-1.49 to -1
Severe drought	-1.99 to -1.5
Extreme drought	<= 2

***Source** : Extract from the table proposed by Mckee, et al., 1995*

The standardized precipitation index "SPI" (Standardized precipitation index) was developed in order to characterize the precipitation deficits for a given period (Mckee et al., 1993). It takes into account the importance of time in the analysis of the availability of water resources.

- **Study of flood variability**

The analysis of the variation in floods (which is moreover more recurrent in the study environment) was carried out through the study of the flood flow regime in the Beninese basin of Pendjari, including the hydrometric station de Porga is the main repository.

- **Study of the flood regime**

For the study of the flood regime in the Beninese Pendjari basin, the flow-duration-frequency method (GAA Atchadé, 2014, p. 69) was adopted. It is a method which involves the duration and the frequency of the interannual maximum flows in the hydrological regime of a watercourse in its basin.

- **Flood characterization**

To characterize the floods, the flood coefficient of Myer-Courtage-Padré (1968) was calculated on the series of flood discharges previously constituted. Its formula is:

$$A = \frac{Q}{\sqrt{S}}$$ with

- A: flood coefficient
- Q: gross maximum flow
- S: surface area of the receiving basin

The calculation of this coefficient made it possible to analyze the power of floods per year in the basin. Thus, the years are qualified according to the power of the floods according to the thresholds below. Let A be the Coefficient.

- ✓ 0 ≤ A ≤ 5: year of low flood
- ✓ 5 ≤ A ≤ 30: year of average flood;
- ✓ 30 ≤ A ≤60: year of high flood
- ✓ At ≥ 60: year of very strong flood.

3. Results

3.1 Daily variation of rainfall in the Beninese basin of Pendjari in Porga from 1965 to 2017. The Figure 2 shows the variation of the daily rainfall regime implying the ecological risk over the period from 1965 to 2017.

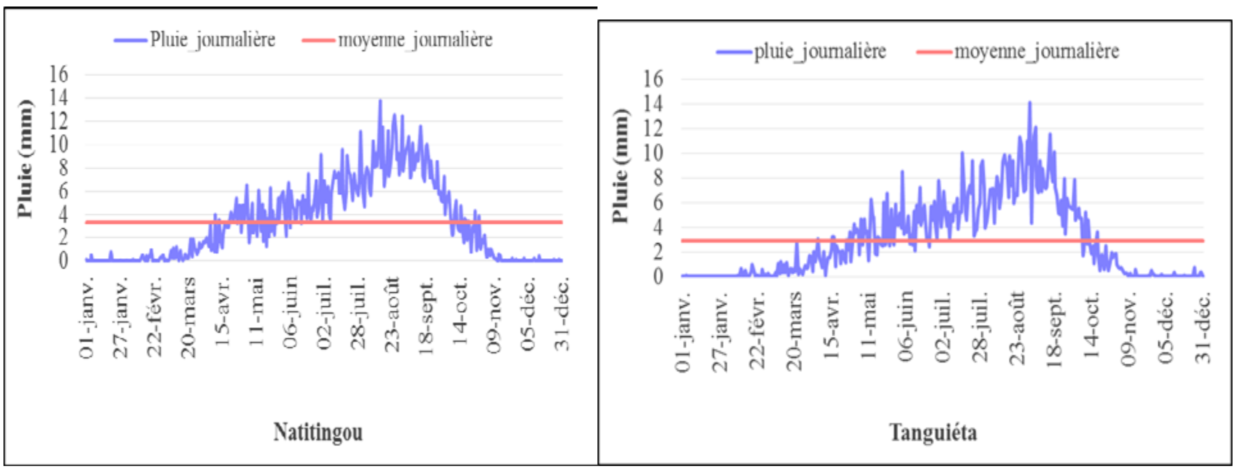

Figure 2: Daily evolution of rain in the Beninese basin of Pendjari a Porga from 1965 to 2017

From the analysis of this figure 2, it emerges that the peaks are recorded in August, making this month the wettest of the year in the basin.
Therefore, it must be deduced that the rainfall regime in the Beninese basin from Pendjari to Porga is a unimodal regime. It is characterized by two seasons, including a rainy season and a dry season with an average that varies from 3.3 mm of rain at the Natitingou station and 2.9 mm of rain at the Tanguiéta station. The lowest values are recorded during the days of the first months (January, February and March) reflecting early rains and those of the last two months (November and December) indicating late rains.
Moreover, from the analysis of this figure, it should be emphasized that the daily peaks above and below the daily average evoke periods of surplus and deficit respectively.
These extremes are likely to induce an ecological risk. Indeed, the deficit period causes a decrease in flow in the Pendjari basin with the corollary of the water turbidity accentuating the presence of substances harmful to the aquatic ecosystem. The same is true for excess rains which contribute to the onset of floods causing flooding and damage in socioeconomic, environmental and health terms.
The influence of rainfall variability on surface and underground water resources is demonstrated by hydrological fluctuations.

➢ Interannual variability of maximum daily rainfall amounts

Figure 3 shows the interannual evolution of maximum daily rains in the Pendjari basin at the Tanguiéta and Natitingou stations.

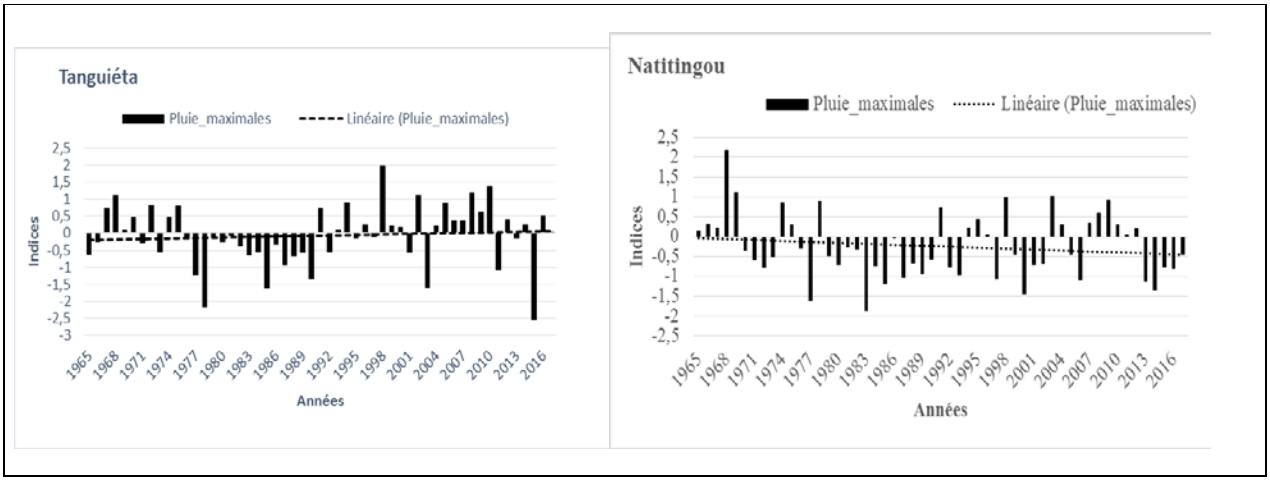

Figure 3: Interannual variation of maximum daily rainfall in Tanguiéta and Natitingou from 1965 to 2017

From his analysis, it emerges that on all four stations, there have been years when the maximum rainfall is likely to cause flooding. The years having recorded the "record" values of maximum rainfall for the various stations are 1977 in Tanguiéta with 174.1 mm and 1970 in Natitingou with 107.1 mm. Overall, the Beninese basin of Pendjari is experiencing a downward trend in maximum values at the level of the Natitingou pluviometric station, but on the other hand this trend is stable at the level of the Tanguiéta station. These extremes are likely to induce an ecological risk and contribute to the advent of floods causing flooding and damage both on the socioeconomic and environmental levels.

- **Interannual variability of maximum daily flows in the Beninese basin of Pendjari in Porga from 1965 to 2017**

The maximum values of the above-average flows recorded at the Porga hydrometric station, made it possible to identify the years of floods which are the causes of the floods during the period 1965-2017 (figure 7).

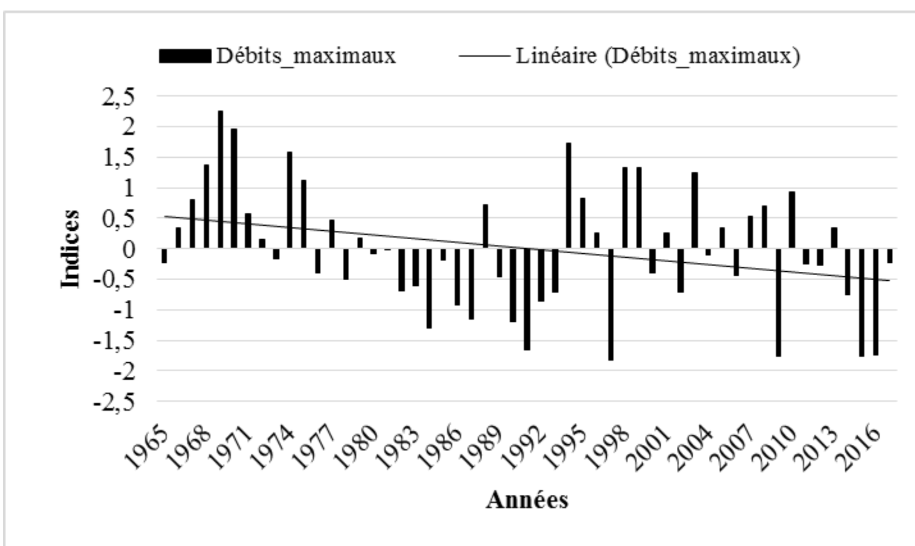

Figure 4: Interannual variability of maximum daily flows
Source: *DG-Eau, 2020*

The analysis of figure 4 reveals that the Beninese basin of Pendjari experienced 23 years of flooding during the period 1965-2017. The strongest flows were recorded in 1969 (588.79 m3 / s) and 1970 (625.2 m3 / s). The lowest floods were recorded in 2001 (286.29 m3 / s) and in 2005 (283.6 m3 / s). The analysis in Figure 4 also shows that the basin has recorded low flows in recent decades and therefore less severe flooding. This is justified by the downward trend in maximum flows in the Beninese basin of Pendjari.

The study also addressed the years marked by extreme flows and during which the activities of the populations are disturbed. The analysis of the flood coefficients presented in Table II made it possible to better characterize this phenomenon.

Table II: Thresholds of flood coefficients according to years

	Low flood year	**Average flood year**	**Year of high flood**
0≤Q≤5	1976, 1984, 1986, 1987, 1990, 1991, 1997, 2009, 2014, 2015, 2016		
5≤Q≤30		1965, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1985, 1988, 1989, 1992, 1993, 1994, 1995, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2017	
30≤Q≤60			None

It emerges from the analysis of Table II, that the Beninese basin of Pendjari is marked in general by the average floods and the weak floods over the period going from 1965 to 2017. It allows to deduce that the floods observed in the Beninese basin from the Pendjari to Porga are average floods that caused flooding especially during the years 1968, 1969, 1998, 2002, 2008 and 2010 which correspond to periods of extreme and high humidity according to the results of the classification of standardized precipitation indices of the table IV. This makes the middle the effects of flooding.
Overall, when we compare the evolution of maximum rainfall levels and maximum flows, we realize that the Beninese basin of Pendjari is experiencing less and less severe flooding. This situation is due, according to the producers, to the decrease in the number of rainy days. On the other hand, producers say they are increasingly faced with drought. The prolonged decrease in precipitation has had sometimes serious effects on runoff.

- **Characterization of hazards based on the rainfall-runoff correlation in the Beninese basin of Pendjari in Porga from 1965 to 2017**

Figure 5 shows the values of the correlations calculated between rainfall and flow.

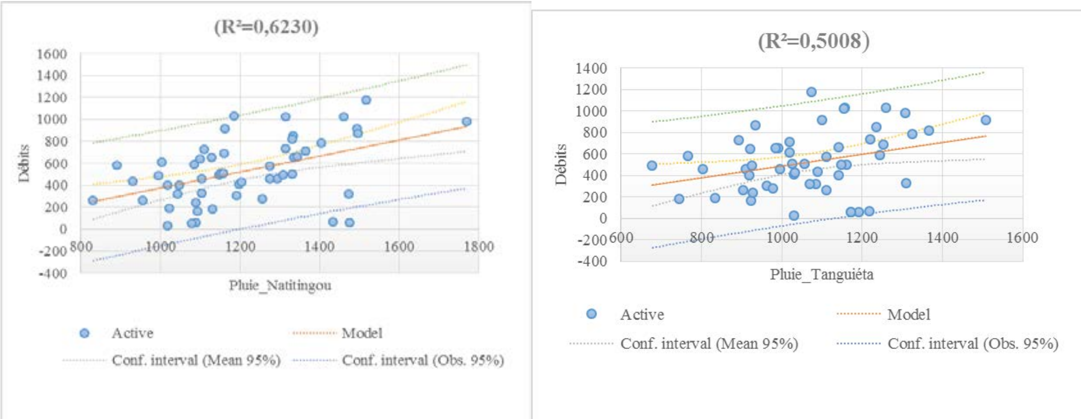

Figure 5: Correlations between flow and rain at Natitingou and Tanguiéta stations

From the analysis of Figure 5, it should be remembered that the rainfall-runoff correlation is established at the scale of the Beninese basin from Pendjari to Porga. As a result, a link is observed between precipitation and flow rates at the various stations. Correlation coefficients of the order of (0.62) are recorded for the Natitingou station and (0.50) for the Tanguiéta station, which makes it possible to say that the layers of water precipitated in the basin constituteindicators that induce the risk of flooding in the Beninese basin of Pendjari in Porga added to the state of land use of the bed of rivers (photo 1).

Picture 1: Occupation of a river bed in the Pendjari basin
Shooting: P. Ouassa, August, 2017

This photo 1 shows how the river beds are occupied by producers in search of fertile land for crops. Thus, agricultural activities at the level of river beds contribute to their filling and amplify the floods in the basin.

However, it should be noted that in the Beninese basin of Pendjari, in addition to the floods and floods, other hydroclimatic hazards disrupt the activities of the populations. These are particularly drought episodes that should be characterized.

- **Characterization of drought**

The SPI calculation was used to characterize the level of severity of the rainfall deficits observed and to assess the extent of drought or humidity (Table III).

Table III: Classification of years according to the SPI in the study environment

	Types of years					
Events	**Extreme humidity**	**High humidity**	**Moderate humidity**	**Moderate drought**	**Severe drought**	**Extreme drought**
Natitingou	1968	1969, 2003	1965, 1966 1967, 1974 1975, 1978 1991, 1994 1995, 1996 1998, 2004 2007, 2008 2009, 2010 2011, 2012	1970, 1971 1972, 1973 1976, 1979 1980, 1981 1982, 1984 1986, 1988 1989, 1990 1992, 1993 1999, 2001 2002, 2005 2015, 2016 2017	1977, 1983 1985, 1987 1997, 2000 2006, 2013 2014	Any
Effective	**01**	**02**	**18**	**23**	**09**	**00**
Percentage	**1.89%**	**3.77%**	**33, 97%**	**43.39%**	**16.98%**	**00%**
Tanguieta	Any	1968, 1998 2002, 2008 2010,	1967, 1969 1970, 1972 1974, 1975 1991, 1993 1994, 1996 1999, 2000 2004, 2005 2007, 2006; 2009 2012, 2014 2016, 2017	1965, 1966 1971, 1973 1976, 1979 1980, 1981 1982, 1983 1984, 1986 1987, 1988 1989, 1992 1995, 1997 2001, 2013	1977, 1985 1990, 2003 2011,	1978, 2015
Effective	**00**	**05**	**21**	**20**	**05**	**02**
Percentage	**00%**	**09.43%**	**39.63%**	**37.74%**	**09.43%**	**03.77%**
Medium	**0.95%**	**6.60%**	**36.80%**	**40.57%**	**13.21%**	**1.89%**

***Source**: Data processing 2020*

From the analysis of Table III, it emerges that the Beninese basin of Pendjari recorded 0.95% years with extreme humidity, 6.60% years with high humidity, 36.80% for years with humidity. moderate, 40.57% years with moderate drought, 13.21% years with severe drought and 1.89% years with extreme drought. The types of rainy years recorded are heterogeneous from one station to another. It should be noted that for the entire 1965-2017 series, there was one year (1968) of extreme humidity and two years (1978, 2015) of extreme drought, which favors the existence of hydroclimatic risks in the Beninese basin of Pendjari in Porga.
This variability of extremely dry and extremely wet years in the Pendjari watershed can have negative impacts on certain human activities such as agriculture, which is a very important source of food for the population of the basin.

3.2 Manifestation of extreme hydroclimatic events in the Beninese basin of Pendjari

- **Flood manifestation**

The excess of rain is characterized by regular and abundant rains over several days throughout the basin and perceived by 46% of the peasants. These are large drops that sometimes fall during a week. The peasants are witnessing the loss of crops due to the flooding of crops. Indeed, the losses of the crops produced are observed during flooding of fields caused by heavy rains on the one hand and by floods of the Pendjari stream and its tributaries on the other hand. According to the producers we met, the rainwater destroys the crops, sometimes even washing them away. Plate 1 shows a rice field flooded by flooding from the Pendjari stream at Toucountouna and flooding from the Magou river at Tanguiéta.

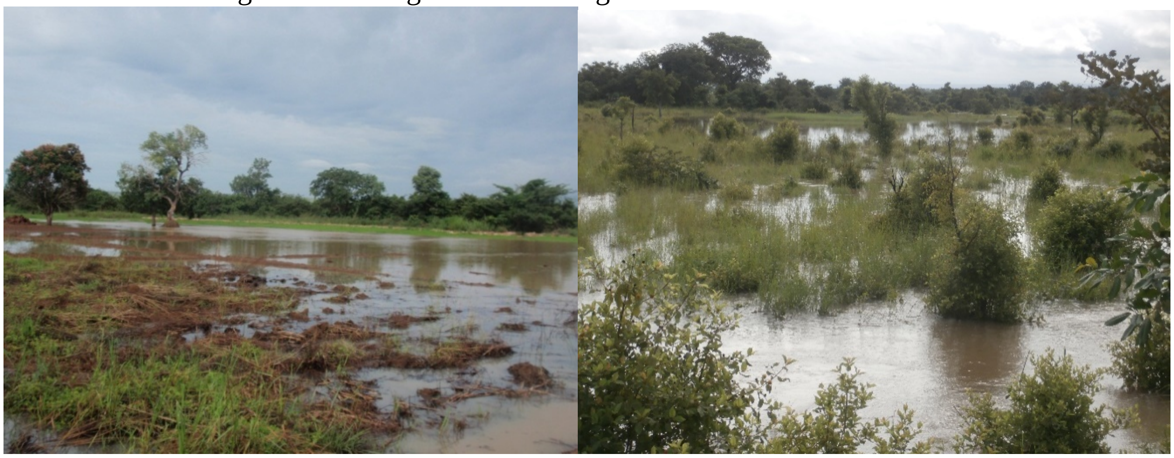

Plate 1: Flooded rice field in Toucountouna and flooding of the Magou river in Tanguiéta
Pictures taken: P. Ouassa, August 2017

This plate 1 shows the behavior of rivers towards crops. Indeed, these watercourses destroy the crops located at the level of the banks. This leads to huge production losses and the drop in yields observed in the Pendjari basin in Benin. This situation is more evident in the months of August and September, which record the peaks of rainfall in the Beninese basin of Pendjari.

- **Manifestation of pockets of drought**

Like floods, pockets of drought also cause production losses. Photo 2 shows a rice field destroyed by the drought pocket in Tampègré.

Photo 2: Manifestation of pockets of drought in Tampègré
Shooting: Ouassa, August 2017

Pockets of drought are characterized by rains in the middle of the rainy season. These rains have been observed throughout the Beninese basin of Pendjari every year for decades and lead to poor crop yields.

In addition, pockets of drought lead to delayed, incomplete and irregular emergence of crops, thus creating heterogeneous defective stands until harvest. It also leads to poor and superficial root establishment of crops. In addition, according to the producers (78, 63%), the late arrival of the rains leads to a persistence of drought which is a source of heat. And it is this heat which would be at the origin of the loss of seeds buried in the ridges.

4. Conclusion

This study shows that the Beninese basin of Pendjari in Porga experiences an interannual variation in rainfall characterized by an alternation of wet period and dry period. These alternations of wet and dry periods constitute periods of hydroclimatic risks. The hazard characterization was also done by the rainfall-discharge relationship which was established at the basin scale, and indicates a good correlation between precipitation and the average recorded discharge. Also the agro-climatic diagnosis showed that rainfall variability has consequences on the agricultural production system. The speculations developed in the basin suffer as much from deficits as from water surpluses. So to reduce the direct or indirect harmful effects of the climate on the agrifood system,

5. References

AGHRAB Abdallah. (2003): Characterization of drought and development of climatic indicators for its early warning in the region of Saïss. End of studies thesis. National School of Agriculture of Meknes, Morocco. 16p.

ATCHADE Assaï Akinni Gervais (2014): Impacts of climate dynamics and land use on the water resources of the watershed of the river Zou in southern Benin. Single Doctorate Thesis, EDP / FLASH, UAC, 235p.

DIOUF Birame, LO Henry M., DIEYE Bounama, SANE Oumar, SARR Ousmane F. (2014): For smart agriculture in the face of climate change in Senegal: collection of good adaptation and mitigation practices. Working Paper No. 85, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), 181p.

IPCC (2007): 2007 Climate Change Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Editorial Team, Pachauri, RK and Reisinger, A. (edited by ~) . IPCC, Geneva, Switzerland,…, 103 p.

HAMDANE Abdelkader (2015): Climate change and food security in the Mediterranean and West Africa: Strategies for agriculture, territories and sustainable growth - Tunisian case study. SESAME seminar, 25p.

HOUNDENOU Constant (1999): Climate variability and corn farming in humid tropical environments: the example of Benin, diagnosis and modeling. Doctoral thesis in geography, UMR 5080, CNRS "climatology of tropical space", University of Burgundy, climatology research center, Didjon, 341 p.

EDIETI Edouard M'po (2012): Hydro-ecoregions of the Pendjari Basin in Benin: Analysis of socio-economic and environmental determinants of the dynamics of natural ecosystems. PhD thesis in geography. University of Abomey-Calavi229 p.

KIMBA Yao. Guillaume (2011): Impact of rainfall variability on water resources in the Pendjari basin. Master's thesis in geography, FLASH, UAC, 67 p.

KOUDAMILORO Olivier (2017): Vulnerability to hydroclimatic risks and adaptation strategies of populations in the Ouémé watershed in Bétérou (Benin). Unique doctoral thesis in geography. Ouaga University 1 PR Joseph Ki-Zerbo, 274p.

UNEP (2011): Livelihood Security Climate Change, Migration and Conflict in the Sahel. ISBN: 978-92-807-3230-6, 112p.

SYLLA Mouhamadou (2017): Establishment and analysis of the baseline climatological situation and climate change scenarios for the Economic Community of West African States. Technical report prepared for the project of the Institute of Natural Resources in Africa of the United Nations University entitled "Climate change, agricultural trade and food security in ECOWAS", 23p.