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CLIMATE VARIABILITY AND SURFACE WATER DEPARTURE AT THE CATCHMENT OF THE RIVER ZOU IN BENIN (WEST AFRICA)

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ABSTRACT

The effects of climate on water resources can lead to one of the serious crises that humanity will face in the coming decades if the trend is not reversed in terms of current climate parameters. This study examines the effects of current climate conditions on the hydrological functioning of the river zou catchment in Benin. The rainfall, hydrological and thermometric data collected at the meteo-Benin agency and at the hydrology department of the General Directorate of Water over the period (1965-2015) made it possible not only to analyze the current rainfall trends, but also to appreciate the hydrological behavior of this watershed. In order to establish a link between the nature of the geological substratum and the availability of surface water in the study area, the temporal evolution of the recession coefficients and the dry period of the water course were estimated at from the law of Maillet.

The analysis of the results shows that the catchment area of the Zou River is characterized by a significant fluctuation of its climatic parameters in recent years. The latter is illustrated by the observed negative rainfall anomalies of the 1970s, 1980s and a thermometric warming trend in the catchment. Between 1965 and 2010, mean annual temperatures increased by approximately 3.77 ° C and 1.71 ° C (Tmax and Tmin to Savè) and 2.04 ° C and 1.19 ° C respectively. (Tmax and Tmin to Bohicon). The aforementioned factors associated with the nature of geological formations have a differential influence on the availability of surface water in the basin. Indeed, the dry-off coefficient is on average 0.019 d-1, duration of about 112 days at Domè (more spread over time) which is on sedimentary formations, while it is 0.046 d-1 45 days to Atcherigbe (faster) which is on the (plinth).

***KEYWORDS**: Zou River Catchment (BVRZ), Climate Variability, Coefficients Recession, Surface Water Resources*

Article History

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INTRODUCTION

The sometimes exceptional nature of drought events is a major challenge for the international and especially African community in terms of their effects on the surface and underground water resources of our various watersheds. Thus, at a time when droughts and water shortages may become more intense in temperate regions, interest in low flows is growing in the scientific community (Driessen et al., 2010; Verstrate., 2011). Indeed, the needs for water to satisfy the different human uses that are growing at the rate of economic development of our countries require a better knowledge and monitoring of the behavior of our water courses and bodies. Africa is now at the forefront of the issue of the impact of climate fluctuations on water resources (Kanohinet al., 2009). Indeed, the climate situation in West Africa in recent years has been marked by a repeated drought that became more exacerbated in the 1970s and 1980s. Rivers, lakes and rivers are at their lowest levels, with some even drying out (Fink, 2007). This drought has been widely described and analyzed by many authors such as Brou (1997), Vissin, Houndénou, Perard (2007), Atchadé (2014) etc. It is the largest and most continuous in the Sahel region (Sircoulon 1974). In sub-Saharan Africa, as in many states of the world, possible changes in the river hydrological cycle appear gradually after a long period and under varied hydroclimatic conditions (Wesselink et al, 1995). Rainfall deficits, observed globally in recent years, both in the Sudan-Sahelian and tropical wetlands, have had a significant impact on the water resources of these regions. Similarly, analysis of the main drying of rivers and rivers has shown a significant increase in the drying coefficient, i.e. a much faster draining of aquifers from basins supplying the base flow (Olivry, 1997), the memory effect of the depletion of underground reserves explains the persistence of changes in hydrological regime variables.

In Benin, there has been a disruption of the overall water cycle in recent decades as a result of severe droughts (Tapsoba 1997). These rainfall recessions resulted in an average 40% decrease in runoff in the Upper Umeta watershed (Tapsoba, 1997). The Zou basin, a sub-basin of the Ouémé watershed (Atchadé, 2014), had experienced water stress of climatic and anthropogenic origin along with all the basins of Benin (Le Lay, 2006). The objective of this study is the characterization of climate variability and its impact on the drying up of surface water in the Zou River watershed in Benin using statistical and hydrological methods.

Geographical and Geological Framework of the Environment Study

Located between 7°15’ et 8°33’ of north latitude and between 1°35’et 2°14’of east longitude (Figure 1), the course of the Zou river shelters two hydrometric stations namely, that of the Zou in Atchérigbé drained by a base formation (Atchadé, 2011) and that of Domè which is on a recent sedimentary cover of a sandy clay and sandstone nature (Boko, 2004).

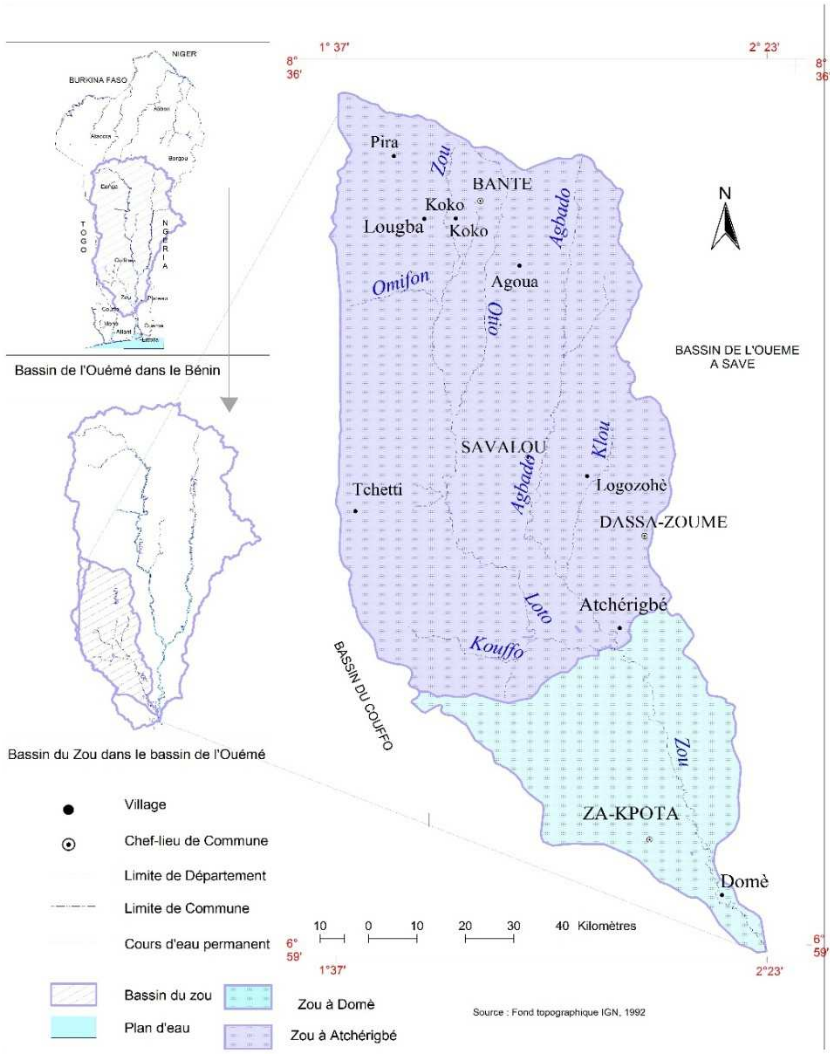

Figure 1: Geographical Location of the Zou Basin.

Indeed, the upstream part of the basin (Sub-Achérigbé sub-basin) as presented by figure 2 is built mainly on the crystalline and crystallphyllian plinth where the supply of drinking water is made from the alterite sheet, cracks and open fractures

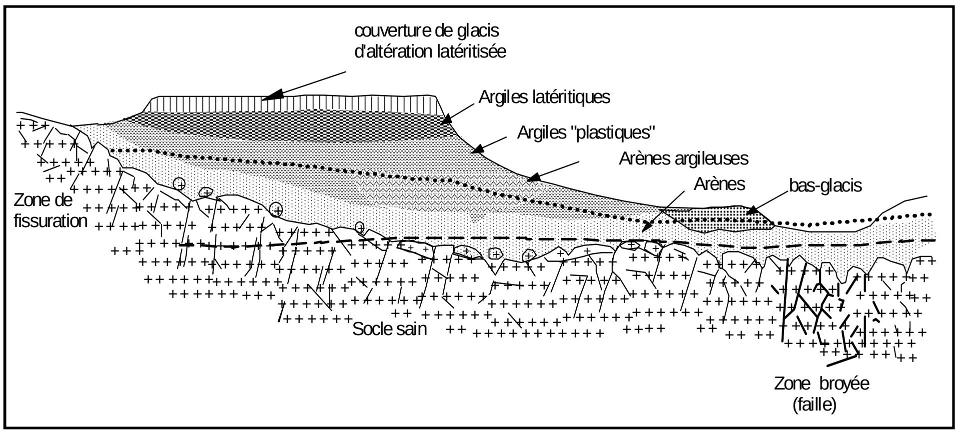

Figure 2: Schematic Section (E-W Oriented) of Altered Aquifer Formations on Migmato-Gneissic and Granitic Rock (Guiraud R., 1988).

The southern portion is based on the series of sediments in the coastal sedimentary basin (upper cretaceous) marked by recent sediment cover above the crystalline base, which is rated approximately 2% to the south. These are sandy-clay formations, waterproof marl clay, fine white sands with coarse aquifers and others (Figure 3).

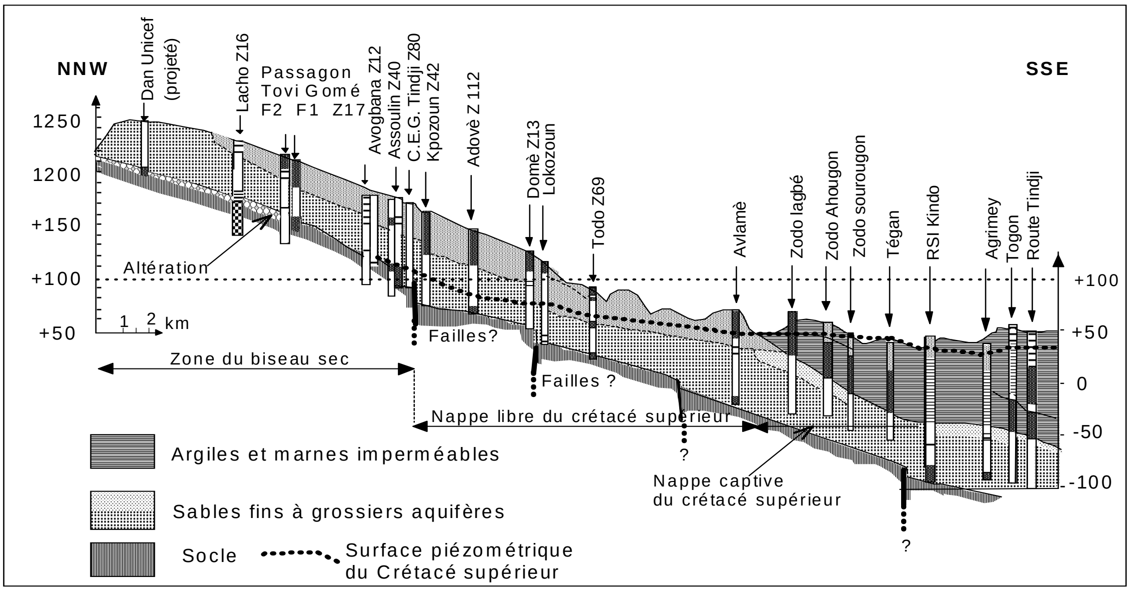

Figure 3: Section Showing the Sterile Zone ('dry bevel') of the Turonian-Coniacian at the Level of the Abomey Plateau (Geohydraulic-BUcRGEAP, 1988).

DATA AND METHODS USED

Nature and Source of Data

The data used for this study are:

- Climatological statistics: rainfall depths and monthly and annual temperatures of the rainfall stations located in the Zou basin or in its very immediate surroundings (Bantè, Pira, Tchètti, Savalou, Glazoué, Bohicon, Abomey, Zagnanado) over the period 1965- 2015 were collected at the Weather Agency-Benin and at the Pierre PAGNEY Laboratory (LACEEDE) of the University of Abomey-Calavi;
- Hydrometric statistics (monthly flows from Zou to Atchérigbé and Domè over the period 1965-2015) were taken from the databases of the Hydrology Department of the General Directorate of Water.
- Data on the geological formations of the study environment are taken from the geological map of Benin published in March 1989-sheet Abomey-Zagnanado at 1/200,000th (Project F.E.D. N 5100-11-13-015) and the hydrogeological map of Benin, scale 1/500,000th, (Geohydraulique, Maisons Alfort, France, Hainque-Perin, Paris, France, 1985).

Data Processing Methods

Study of Climate and Hydrological Variability in the Basin

Rainfall and thermometric variability is characterized from some techniques and methods of diagnostic climatology such as determining the reduced centered anomaly or the annual rainfall index with the formula:

$$SPI_i = \frac{x_i - \bar{x}}{\sigma(x)}$$

It reflects a deficit or surplus situation relative to normal

With Xi: rainfall of the year i; i ; $\bar{x}$: inter-annual average rainfall over the reference period and: $\sigma(x)$ the standard deviation from inter-annual rainfall. The latter were used in the detection of dry or loss-making years and wet or surplus years over the reference period.

Determination of the Layer of Water Flowing in the Basin

To assess with great precision the blade passed over the Zou basin at Atchérigbé and Domè, it is necessary to determine the flows caused by the rains that fell during the period. The assessment of flows in the study environment was based on the following formula:

$$Le = \frac{V_{ec}}{S}.10^{+3}$$

With V_{ec} = Qt. Q corresponds to the flow of the basin (m3/s), S: area of the basin and t time (s). The flow coefficient, for example, allows the hydropluviometric behaviour of sub-basins to be analysed.

Determining the Flow Coefficient

The flow coefficient reflects the runoff capacity of the basin. This coefficient is closely related to climatic variations and reflects the relationship between rains and runoff (Mahé and Olivry 1995). It is determined from the formula:

$$\alpha = \frac{C}{P} X_{100}$$

Which reflects the runoff capacity of the basin, with C the flow and P the rain. C evolves according to climatic variations and highlights differences in behaviour between rains and runoffs. Its usefulness in this study lies in the fact that it also allowed to analyze the role played by each of the geological substrates in the level of availability (differential hydrological functioning) of the water resources of the two sub-basins of the Zou River.

Study of Drying Out in the Study Environment

The observation of the evolution of a decline from a certain stage of the annual hydrogram, shows the steady decline of natural flows (or drying phase). This is the period during which groundwater draining is the only contribution to the flow of streams in a basin. Since during periods of low water flow are only provided by the emptying of aquifer reserves, this input can be analyzed from the drying. This allows us to approach the rate at which aquifer reserves are drained from different laws that propose to calculate a drying coefficient (Dewandelet al., 2003). To calculate this coefficient, the choice was made on Maillet's law, which is most commonly used (Tallaksen, 1995) and is determined by an exponential equation:

$$Qi = Qoe^{-i\alpha(ti-to)}$$

Where Q_0 is the initial flow of the drying period, Qi the flow after a t time and the angular coefficient of the drying right. tiet to expressed in days, and α coefficient of employment depending on the physical and geometric characteristics of the aquifer, whose lavatory is the opposite of time:

$$\alpha = \frac{1}{T}$$

The assessment of α in the Zou basin can be made by analyzing the beam of hydrograms observed at the various hydrometric stations (Atchérigbé and Domè) during the period of low water, hydrograms reported on a graph. Qo's determination is to identify a phase of flow that we will call hinge, which can be used as a starting point for drying up. This point is on the recession curve and should not be far from the high water period so that, by close correlation, the flow to the rains of the corresponding period can be compared. This method, already used by several authors including Le Barbé et al. (1993) and El-Ouafi (1993), Amoussou (2010) made it possible to determine on the Zou watershed the temporal evolution of the drying coefficients and to assess the drying duration of this river. When the values of the observed flows (in logarithmic scale) are ordered and the time-to-day is abscised, the elements of the calculation are graphically obtained. Maillet's law clearly accounts for the decrease in the flow of a stream when the stretches are fed by a simple and homogeneous tablecloth. The methodological approach adopted resulted in the results presented below.

RESULTS AND DISCUSSION

Inter-Annual Variability in Rain Heights and Temperature

Rainfall Trend

The analysis of inter-annual variability in rain heights shows that the Zou basin experienced a significant decrease in rainfall in Atchérigbé as well as Domè from 1965 to 2015 (Figure 4).

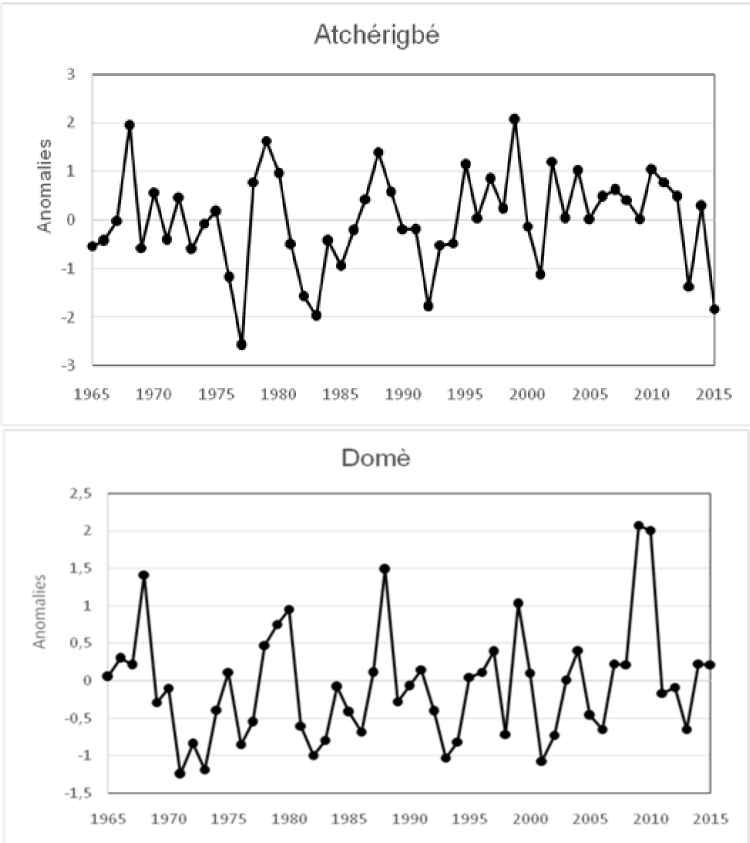

Figure 4: Interannual Variability of Rain Heights in the Zou Basin at Atchérigbé and Domè (1965-2015).

In view of the negative rainfall anomalies observed, the 1970s and 1980s were generally in deficit throughout the basin. This finding shows that droughts in West Africa in the 1970s in general affected Benin and the entire Zou basin. This situation has not been unseating on the hydrological behaviour of the Zou River watershed.

Thermometric Trend

The analysis of temperature change is of interest in this study because this parameter influences the evaporating power of air and is a determining factor in the hydrodynamics of underground reservoirs (Totin, 2010). The analysis of interannual changes in maximum and minimum temperatures (Figure 5 and 6) shows a warming trend in the basin for the period in question.

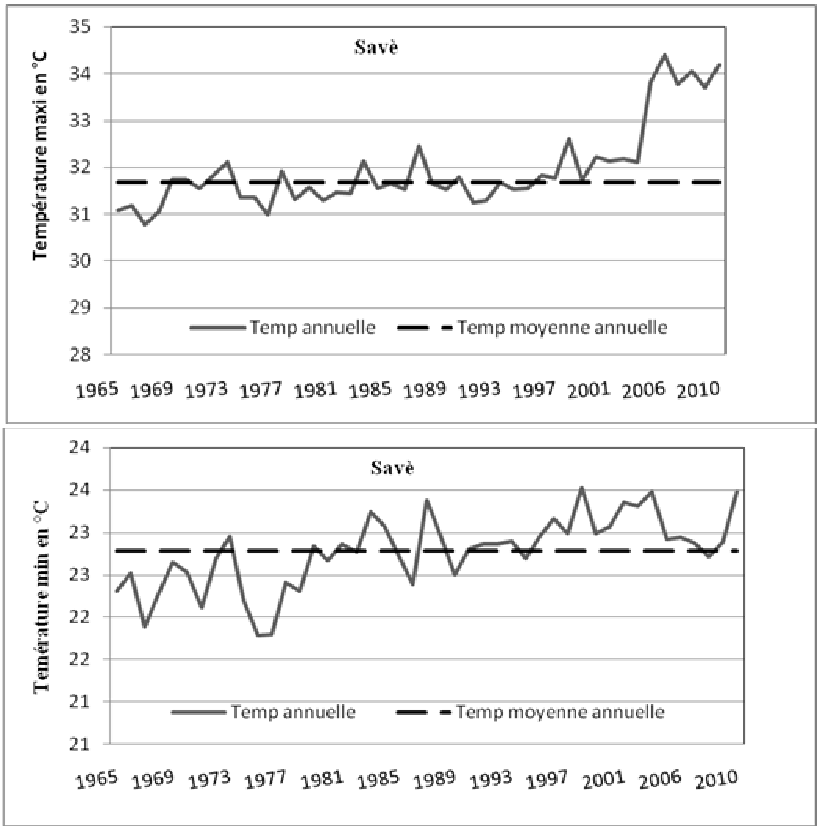

Figure 5: Interannual Change in Mini and Maximum Temperatures at the Synoptics Station of Savè from 1965 to 2010.

Overall, average annual temperatures fluctuated over the study period. Overall, they rose from 30,40 °C in 1965 to 34,17 °C in 2010, with an increase of 3, 77 °C for maximum temperatures and from 21.79 to 23,47 °C, or 1.71 degrees Celsius for mini temperatures at the Savè station. In Contrast, in Bohicon, average annual temperatures rose from 31, 29 °C in 1965 to 33, 33 °C in 2010, an increase of 2, 04 °C for maximum temperatures and from 22.19 to 23,38 °C, or 1,19 ° C for mini temperatures. Overall, it is therefore remembered that this warming is felt more in the upstream part than in the downstream part of the basin.

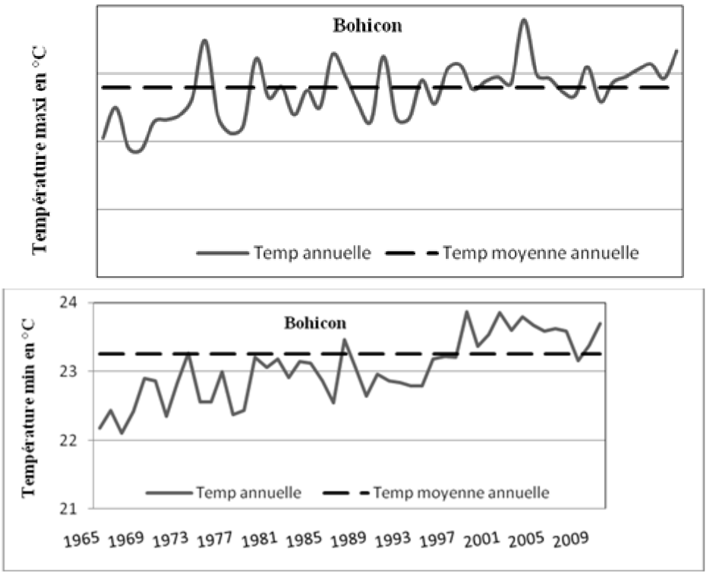

Figure 6: Inter-Annual Change in Mini and Maximum Temperatures at Bohicon Synoptic Station from 1965 to 2010.

This raise in temperatures observed locally over the entire Zou basin is greater than that of the IPCC (2007) i.e. 0.2 to 1 °C for Benin. This makes it possible to assert that the average values of specificities can be observed when changing spatial scale. The increase in temperatures coupled with the rainfall fluctuations noted above could be detrimental to the availability of water resources in the study environment due to an increase in the evaporating power of the air.

Variability in Flow Coefficients on Different Formations

Figure 7 showing the variation in annual flow coefficients (1965-2015) shows a decrease in average flows over the period 1971-87 over the basin as a whole compared to the pre- and post-basin periods. The most important flow coefficients are observed at the Atchérigbé station in contrast to Domè station. Indeed, the sub-basin of the Zou in Atchérigbé which rests on rocks less permeable, but more or less furniture and eroded, with a vegetation cover in plain degradation due to anthropogenic activities (agricultural production and agro-pastoral activities) increases the intensity of drainage.

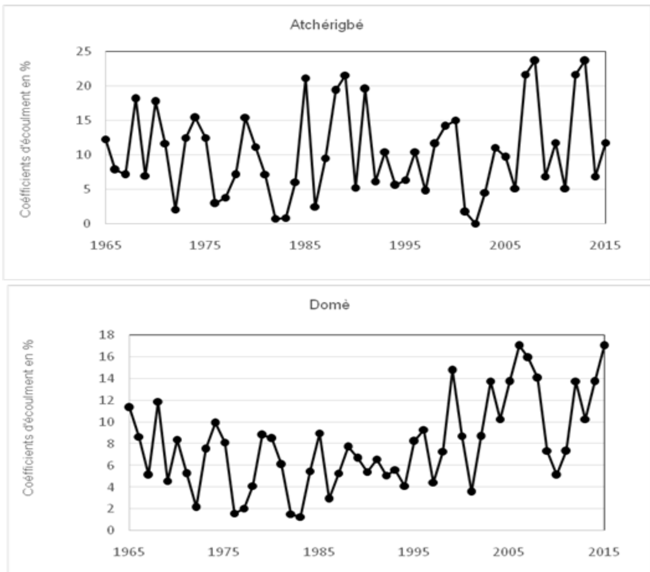

Figure 7: Seasonal Change in Flow in the Zou River Watershed.

The combined effect of the aforementioned aspects and sub-basin morphology with slopes of more than 8% (Bossa, 2007) favours the evaporation and runoff of the sub-basin's surface waters at the expense of infiltration.

On the other hand, the Domè sub-basin, which relies on a formation of permeable or semi-permeable materials with more or less continuous vegetation cover, has a very low drainage density while ensuring better infiltration of surface water that will be used to recharge the water table.

Analysis of the Coefficient and Drying Duration in the Sub-Basins

The change in annual drying coefficients over the period 1965-2015 is presented in Figure 8.

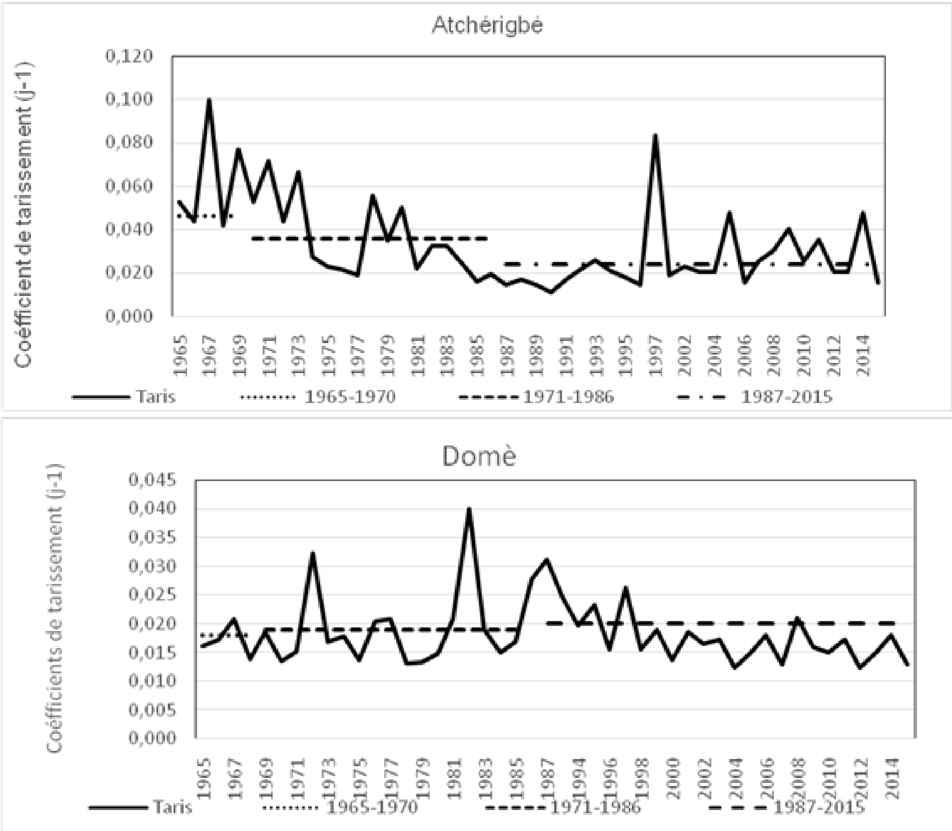

Figure 8: Annual Change in the Drying Coefficient at Atchérigbé and Domè.

The analysis of this figure points to a tendency to increase the coefficient of drying in the sub-basin of Achérigbé, unlike that of the Domè. Indeed, as shown in figure9, in the basin of Zou Atchérigbé, as soon as the rains stop, there is a rapid drying up (about 47 days) until the flow reaches 0.89m/s, where there is a slowdown.

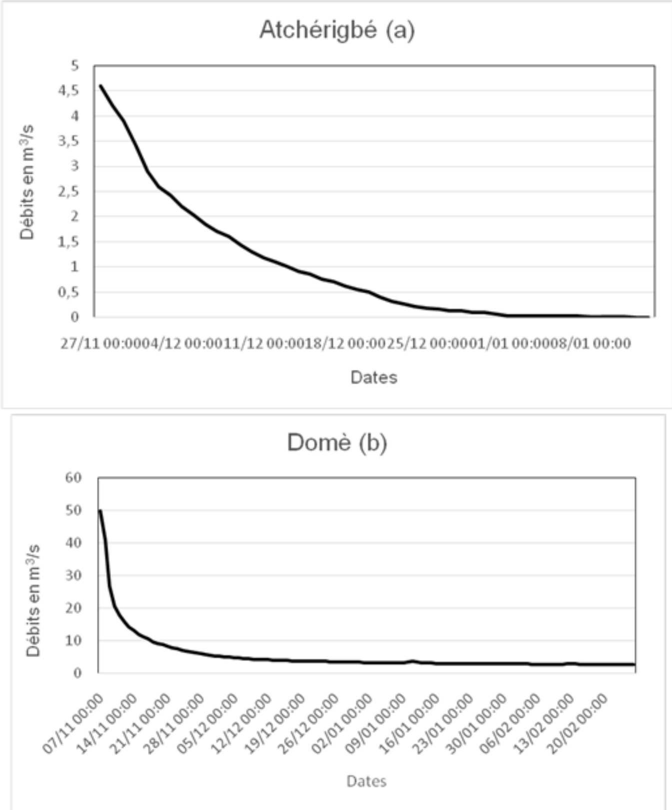

Figure 9: Drying Time on a Pedestal in Atchérigbé (a) and on the Sedimentary at Domè (b).

On the other hand, in Domè, the drying duration is about 112 days. Thus, at the Domè station which is on the sedimentary, there is a slower drying more spread over time with a flow of stretch supported by the underground flow. Across the basin, rainfall deficits are leading to an increasing decline in underground reserves. Thus, the draining of the slicks of each of the sub-basins follows a drying law that grows from one sub-period to the next.

DISCUSSION

Like all of West Africa and Benin in particular, the Zou River watershed experienced spatial-temporal instability in its climatic parameters with more pronounced rainfall deficits over the sub-period from 1971 to 1987. The latter is illustrated by the negative rainfall anomalies observed during the 1970s, 1980s and a warming trend in the basin. This impacts the surface water resources available in the study environment. These results are consistent with those obtained in Benin by Bokoet al., (2004), Vissin (2007) on the Niger and Amoussou basin (2010), in the watershed of the Mono-Ahémé-Couffo and Atchadé river-lagoon complex (2014), which report that rainfall deficits in the 1970s and 1980s have impacted the flows of the various watersheds studied. For Petitjean (2008), the decrease in precipitation is usually accompanied by a decrease in river flow as well as soil moisture levels, which together are the various factors of drought. The study of thermometric trends points to an increase in average annual temperatures of about 3,77 °C et 1,71 °C (Tmax and Tmin in Savè) 2,04 °C and 1,19 ° C (Tmax and Tmin at Bohicon). This same upward trend in temperatures, which has already been highlighted throughout the Benin coastal sedimentary basin by Totin (2010), has not remained inconsequential to the groundwater resources of this environment. The increase in temperature associated with rainfall deficits increases the evaporation loss over the entire basin. In addition to this state of vulnerability of surface water resources, the topographical and geological positions of the study environment in general are added. This explains the differential behaviour of drying coefficients in the study environment with an average of 0.019 j-1, or about 112 days in Domè, and 0.046 j-1 or 45 days in Atchérigbé. But these drying times appear longer than those obtained by Kouassiet al , (2013), which found a shortening of 1 to 9 days with an average of 5 days of drying duration after 1 968 with drying coefficients ranging from 3.14.10-2 to 3.56.10-2 j-1 on both sides of 1968, an increase of 15.26% in the n'zi-bandama (ivory-grade) watershed, which is based on granite formations migmatites and granodiorites. The issues of drying up have also been described for other rivers in tropical Africa by several authors such as Vissin (2007), Amoussou (2010) etc.

CONCLUSION

To round off, it should be noted that the study of climate variability in relation to surface water resources highlights the main factor of climate in the hydrological functioning of the Zou River watershed. Thus, the negative rainfall anomalies observed during the 1970s and 1980s, accompanied by an increase in annual temperatures, impacted surface water availability throughout the Basin. Similarly, the evaluation of the drying coefficients allows highlighting the differential hydrological functioning of each of the sub-basins (Atchérigbé and Domè) of the study environment. As a result, there will be a trend towards increasing the coefficient of drying and a faster and less spread over time in the sub-watershed of the river at Atchérigbé which is on base formations, while the latter appears to be lower with a slower drying and more spread over time at the latitude of Domè which is on sedimentary formations. This differential functioning of the two sub-basins should be taken into account in the implementation of different adaptation or mitigation strategies in the face of current climatic conditions in the major watersheds of Benin in general and that of the Zou River in particular.

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