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CLIMATE VARIABILITY AND ITS IMPACT ON WATER RESOURCES IN THE LOWER MONO RIVER VALLEY IN BENIN FROM 1960 TO 2018

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ABSTRACT

Climate change has an influence on rainfall, which significantly affects the magnitude of the frequency of floods and droughts. Variations in precipitation over the long term are therefore one of the elements of climate variability. To identify the change, the quantification of the environmental change that has already occurred in the Beninese portion of the Mono River Basin (lower valley) and to understand the impact of this change on the water resources of the basin, for a better future adaptation, the annual rainfall and hydrological data for each station in the basin were compiled over a period of 58 years (1960 to 2018). These data were aggregated to the basin scale based on the standardized Lamb anomaly index before being attached to the 2nd order HANNING low-pass filter to extract bright periods over the basin. Then, Pettitt's and Hubert's rupture detection tests at the significance level of the Scheffé test made it possible to study the homogeneity of the different series. Finally, a hydrological balance over each detected period was carried out to determine the real infiltration rate in the underground reservoirs of the basin. The results show that the rainfall regime of the Mono River basin in Benin (lower valley) experienced two breaking points in 1968 and 2007, which show three subperiods: 1960-1968, 1969-2007 and 2008-2018. Thus, compared to the 1960-1968 subperiod, the Beninese portion of the Mono River basin (lower valley) experienced a 21% rainfall deficit period from 1969-2007 and a 10% rainfall surplus period between 2008-2018. The hydrological balance of the basin carried out over each subperiod detected is in deficit. Before the first rupture (1960-1968), the recharge rate in the underground reservoirs of the basin was 12.73%. This rate rose after the first break (1969-2007) to 1.57%. That is, 87.64% of the recharge deficit compared to the reference period and represents more than 4 times the rainfall deficit, against 5.78% of the recharge rate between 2008 and 2018. Through this article, good management of groundwater resources in the lower Mono River valley proves necessary in the case of unfavorable climatic conditions.

Keywords: Rainfall variability, Index, Water balance, Recharge rate.

INTRODUCTION

Climate change is now widely recognized by the scientific community (IPCC, 2013). Its devastating effects in India (Mehta, 2021; Mehta and Yadav, 2022), Bulgaria (Bocheva et al. 2009), France (Renard, 2006), the West Indies (Perera et al., 2020; Leon and Oculi, 2023), the Sahel (Rigaud et al., 2019), the United States and southern and eastern Africa (Rigaud et al., 2019), and media coverage have greatly contributed to sounding the alarm. Climate change is particularly marked, with an intensification of temperature extremes, rainfall anomalies and natural disasters, which each year leave millions of people in danger, injured, homeless or food insecure and cause severe and costly economic damage in Africa (IMF, 2020). A third of drought events in the world occur, for example, in sub-Saharan Africa (IMF, 2020). Researchers (Nicholson, 1998; Paturel et al., 1998; Conway, 2009; Descroix et al., 2018; Koua et al., 2019; Kouao et al., 2020; Nassa et al., 2021) have shown that climate change has an impact on rainfall in several African countries. In West Africa, for example, it started in Sahelian countries with the transition from humid conditions from 1950 to 1970 to dry conditions from 1970 to 1990 before spreading to humid countries. In fact, the transition from humid to dry conditions in the Sahelian countries of West Africa led to a deterioration in surface conditions, resulting in a reduction in the water retention capacity of soils, which in turn led to an increase in runoff coefficients, hence the Sahelian hydrological paradoxes (Dardel, 2014; Gal, 2017; Descroix et al., 2018). This drought in the Sahel has spread to humid countries bordering the Gulf of Guinea, with serious consequences (reduced rainfall, lower piezometric levels, falling river flows, etc.) (Servat, 1999; SORO, 2011).

Benin, like most of the humid countries on the Gulf of Guinea, is not spared from this phenomenon. In 2018, its global disaster risk index ranged from 10.44 to 50.28, ranking it 30th worldwide and 8th in sub-Saharan Africa, with a high level of climatic vulnerability that is 1.9 times higher than that in sub-Saharan Africa, 2 times higher than that in Japan and 1.7 times higher than that in Mauritius (REBPC, 2019). The example of the southwestern part of the Mono River basin in Benin (Fig 1.) in this context of climatic manifestations with two dry and two humid seasons. This basin, whose lower bed is navigable and mostly cultivated with maize, yams and manioc, has seen a decline in water availability in recent years and an increase in potential evapotranspiration (Amoussou, 2010). In addition, it is regularly hit by large-scale floods (Ago et al., 2005) without a major rainfall event. These floods, whether by runoff, overflow or slow flooding (Atiyé, 2017), hit the basin hard, causing enormous damage to schools, health centers, roads, markets, places of worship, agriculture, sanitation and other public goods and services (Ago et al., 2005). The 2020 flood caused 6 deaths and 7000 displaced individuals

(REBPC, 2020), and the 2019 flood caused 46 deaths and a total of 317 576 victims (REBPC, 2019). Finally, the 2011 flood caused 25 deaths, 215 hospitalizations, and 4687,1 homeless victims with a great loss of crops and animals (REBPC, 2011). In 2005, researchers such as Ago et al. linked the high frequency of floods in this part of the Mono River basin (downstream of the Nangbéto Dam) to the return of improved rainfall since the late 1980s, anthropogenic pressures and population growth. These authors showed that the temporal stability of flow and rainfall series from 1955 to 1999 revealed no patterns. E. Amoussou's 2010 test of the temporal homogeneity of annual rainfall series using the SMWDA on precipitated water levels in the watershed of the Mono-Ahémé-Couffo (in Bénin-Togo) river-lagoon complex revealed no major discontinuity in rainfall from 1961-2000 in the south of the complex. Analysis of the hydrometeorological dynamics of the Mono River basin (in Bénin-Togo) and the distribution of incoming floods at the Nangbéto Dam (in Togo) using the GR4J hydrological model on a daily basis to assess flood risk in the lower river valley (in Bénin) between 1988 and 2010 also revealed no patterns (Amoussou, 2015). Studies carried out by Nakou et al. in 2022 to determine extreme rainfall events in the lower Mono River valley in Benin using the ETCCDI-CLIVAR/JCOMM project approach, characterizing intense rainfall to understand how extremes change over the basin, revealed several breaks at different dates. In addition, in 2020, Klassou et al. showed in the North of the basin (Togo) that the disturbances of the rainfall regime on which the hydrological regime of the Mono basin depends are partly determining factors in the vulnerability of riparian communities to flooding. Understanding the disturbances of the rainfall regime in the southern basin in Benin (Lower Valley) and its impact on water resources for appropriate adaptation measures is the objective of this study. The aim of this article is to use more reliable statistical approaches to demonstrate the existence of rainfall variability in the basin and to understand its impact on the basin's groundwater resources between 1960 and 2018.

METHODOLOGY

Presentation of the study area

Bordered to the north by the Ouémé basin, to the south by the Atlantic Ocean, to the west by the Republic of Togo and to the east by the Couffo watershed and Lake Ahémé, the lower Mono River valley in Benin lies between parallels 6° 25' and 7° 75' north latitude and meridians 1°03' and 2°25' east longitude. It lies in southwest Benin at the interface of two hydrological systems, marine and fluvial (Amoussou, 2010) (Fig. 1). This Beninese portion of the Mono River watershed, the subject of our study, covers an area of 2267 km^2 (Atiyè, 2015). The lower Mono valley receives liquid inputs from the sea downstream and from the Mono River upstream (Amoussou, 2010). The degradation of the banks of the Mono River has considerably altered the boundaries of the lower valley.

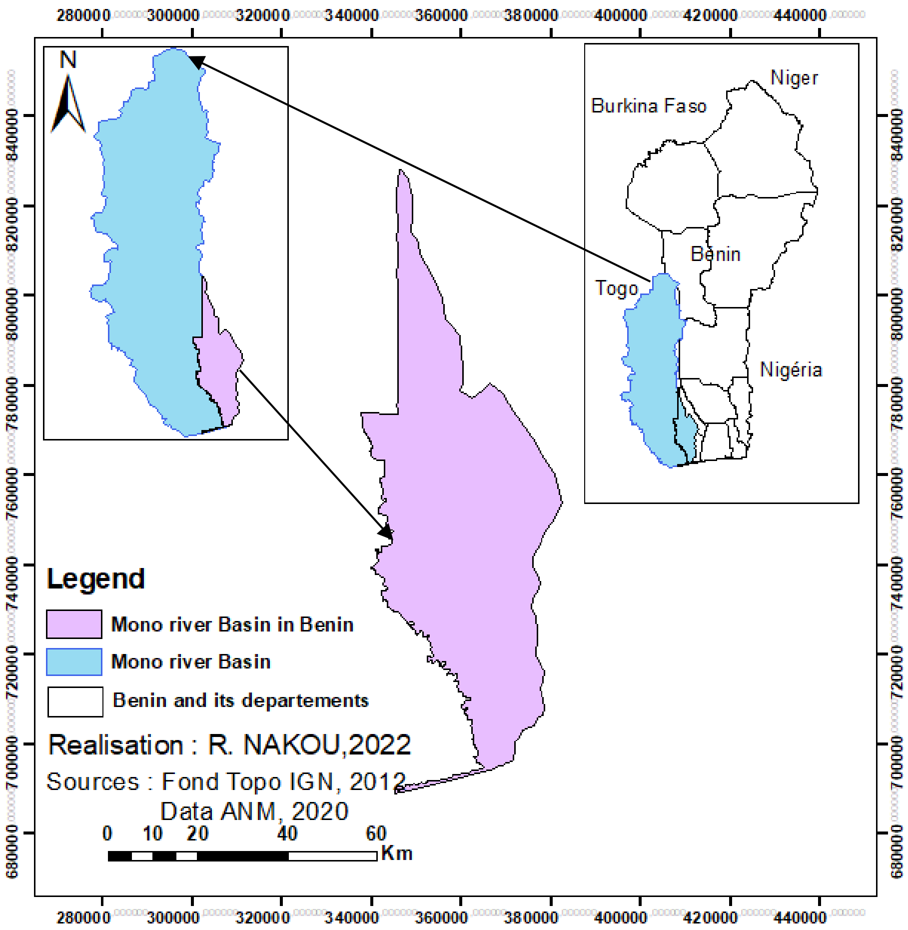


Figure 1: Location of the study area

DATA AND METHODS

Data

A total of 16 rainfall measurement stations with daily data, 8 of which are located within the Mono basin, were used (Fig 2). Most of these data cover the study period (1960 to 2018) and are collected from the Safety Agency and Navigation of Benin. For hydrological data, those from Athiémé (06°35'N and 01°40'E) were the focus of this study. The lower Mono River valley has just one hydrological station, located downstream of all the hydrological stations for Mono. As the lower Mono River valley has no synoptic stations, the temperature data used in this study come from the Bohicon synoptic station (07°10'N and 02°04'E), given the climatic similarities between the basin and Bohicon.

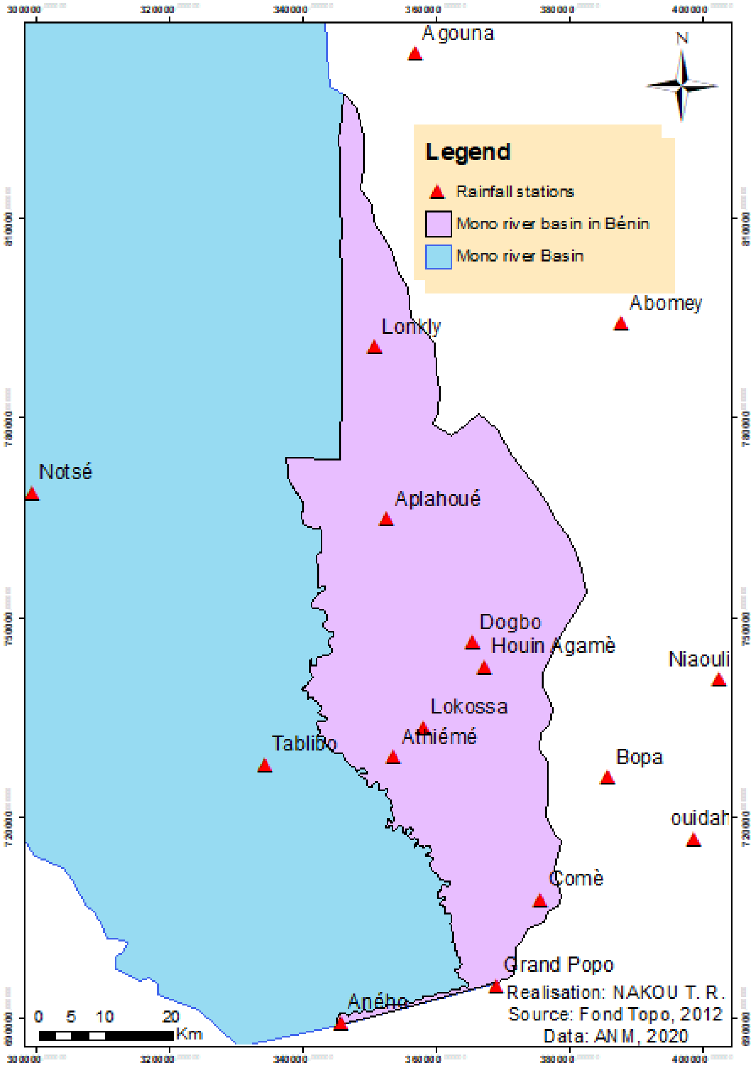


Figure 2: Location of rainfall stations in Benin's lower Mono River valley

METHODS

Lamb's standardized anomaly index (1982)

We first used Pearson's r correlation coefficient to determine the closeness of relationships or degree of correlation between station series to fill in gaps. For stations with a sufficient number of gaps, we determined whether they were certain or accidental to check that taking them into account was not risky. Next, the deviation-from-average index was applied to the weighted series to analyze interannual variability by estimating the annual rainfall deficit. To this end, the annual climatic parameters of each station were globalized at the basin scale on the basis of Lamb's (1982) standardized anomaly index. This index is given by the following equation:

$$X_j = \frac{1}{N_J} \sum_{i=1}^{N_j} \frac{P_{ij} - \overline{P}_i}{\sigma_i} \tag{1}$$

where Pij is the parameter measured in year j at station i, σi are the averages and standard deviations of the parameter recorded at station i and Nj is the number of stations with values for year j.

2nd-order HANNING low-pass filter

The 2nd-order HANNING low-pass filter was applied to Lamb's standardized anomaly index to obtain better observations of interannual fluctuations by eliminating seasonal variations. This method, recommended by Assani (1999), was applied to the basin by Nakou et al. (2022) with satisfactory results. The equations recommended by Assani (1999) are:

$$X_{(t)} = 0.06x_{(t-2)} + 0.25x_{(t-1)} + 0.38x_{(t)} + 0.25x_{(t+1)} + 0.06x_{(t+2)} \quad for\ 3 \leq t \leq (n-2) \tag{2}$$

where is the weighted rainfall total of term t and are the rainfall totals of the two terms immediately preceding term t and are the rainfall totals of the two terms immediately following term t.

The weighted rainfall totals of the first two terms X (1) and X (2) and of the last two terms X(n-1) and X(n) of the series are calculated using the following expressions.

$$X_{(1)} = 0.54x_{(1)} + 0.46x_{(2)} \tag{3}$$

$$X_{(2)} = 0.25x_{(1)} + 0.50x_{(2)} + 0.25x_{(3)} \tag{4}$$

$$X_{(n-1)} = 0.25x_{(n-2)} + 0.50x_{(n-1)} + 0.25x_{(n)} \tag{5}$$

$$X_{(n)} = 0.54x_{(n)} + 0.46x_{(n-1)} \tag{6}$$

Methods for detecting breaks in time series

A break is defined as a change in the probability distribution of a time series at a given, usually unknown, point in time (Lubes, 1994). Its occurrence modifies the rainfall and hydrological regime. Several approaches are used to detect breaks in time series. In this article, we use the nonparametric test of A. Pettitt's (1979) nonparametric test, followed by P. Hubert's (1989) segmentation at the Scheffe significance level because of their robustness.

Water balance study

The hydrological balance of the lower Mono River valley in Benin was determined before and after the first and second break-ups to understand the impact of climatic variability on the basin's groundwater resources. To do this, it is very important to quantify evapotranspiration in the watershed.

The water balance equation is defined as follows:

$$P = E + R + I \pm \Delta S \tag{7}$$

P: Average annual precipitation at the basin level [mm],

S: resources (accumulation) from the previous period [mm],

R: surface runoff and groundwater discharge [mm] obtained from the COUTAGNE method,

E: evaporation (including evapotranspiration) [mm] obtained from Thornthwaite's formula,

S ± ΔS: resources accumulated at the end of the period [mm].

I: incoming volume [mm] over the calculation period.

RESULTS AND DISCUSSION

Study of rainfall variability in Benin's Mono River basin

This part of the work is devoted to analyzing the variability in rainfall parameters in the lower Mono River valley in Benin. Rainfall data observed over the period 1960-2018 are highlighted. This made it possible to isolate periods of heavy rainfall from dry and very dry periods. Fig. 3 shows the interannual evolution of rainfall in the basin (Fig. 3A), with anomaly indices of annual rainfall heights calculated (Eq 1.), (Fig 3B.) and weighted annual rainfall totals obtained from equations 2, 3, 4, 5 and 6 (Fig 3C.) for the Mono River basin from 1960 to 2018. Fig. 3A shows a nonsignificant downward trend (P value >0.05) of 1.84 mm/year in rainfall. This downward trend is clear from 1969 and continued with the preponderance of drought conditions until 1986, with years of significant drought anomalies in 1976, 1977 and 1983 (Fig 3B). The decades 1990, 2000 and 2010 show strong variability, with alternating positive and negative anomalies. To eliminate this strong variation and facilitate interpretation of the graph, we clipped peaks and troughs to smooth the initial curve to reveal a clear trend in precipitation. The method used is the 2nd-order Hanning low-pass filter (Eqs 2, 3, 4, 5, 6) (Fig 3C). Nonparametric break detection tests (Table 1) and Hubert segmentation at the Scheffé test significance level (1%) applied to annual rainfall heights detect 1968 and 2007 as break points. Thus, three subperiods, 1960-1968, 1969-2007 and 2008-2018, with respective averages of 1295.667 mm, 1021.6585 mm and 1125.9485 mm, are formed from these points (Fig 3C). These figures show that the study area has three periods of interannual variability in rainfall indices over the study period. A wet period (the first) is detected between 1960 and 1968, a second deficit period from 1969-2007 and a slight recovery from the mid-2000s. The index method applied to the filtered series (Hanning low-pass) shows that the decline in rainfall in the 1970s continued and intensified until 2007 (Fig 3C.

), making this a period of very low rainfall. The Pettitt test with its U test variable confirms this result (Fig. 4). The same results were obtained in 2016 and 2019 (Amoussou et al., 2016; Yarou, 2019) in the Beninese basin of the Niger River in northern Benin. Rainfall deficits in the 1990s, 1980s and 1970s were 47 mm, 70 mm and 88 mm, respectively, compared with the average and 110 mm for the 1969-1986 subperiod. This drop in precipitation was recently confirmed by R. T. Nakou et al. in 2022 in the basin, where the authors showed a very significant downward trend of 15.40 mm/year in total annual precipitation between 1971 and 1987, accompanied by a downward trend in the number of rainy days. The work of the IPCC (2007) detected the greatest drought of the twentieth century in Africa between 1970 and 1990, which fits perfectly with this trend in the basin. Moreover, the years 1977 and 1983 in the basin (Fig 3A. and Fig 3B.) fall within this IPCC interval, and these same years were identified as the most severe in the work of R. T Nakou et al. (2022). As early as 2010, E. Amoussou described 1983 as "exceptionally deficient". This deficit phase in the basin between 1969 and 1986 partly explains the deterioration in surface conditions, with gallery forests and dense forests decreasing in area, as well as open forests and wooded savannahs, palm-fallow crops and swampy thickets, all of which reduced evaporation and hence the runoff deficit (Amoussou, 2010). Indeed, during this phase, the basin saw a regression of more than 60% in forest formations and wooded savannahs (Amoussou, 2010). The increase in population and anarchic occupation of the basin, quarrying, soil degradation and intensive slash-and-burn agriculture are all significant factors that also explain the degradation of surfaces. The basin's behavior during this phase is the consequence of the extension of the drought that swept through the Sahel, with the transition from wet conditions from 1950 to 1970 to dry conditions from 1970 to 1990, before spreading to the humid countries bordering the Gulf of Guinea, with serious consequences (reduced rainfall, lower piezometric levels, falling river flows, etc.) (Servat, 1999; Soro, 2011).

A closer analysis of Fig 3C. shows that the deficit phase experienced by the basin between 1969 and 2007 is punctuated by a wet cycle between 1987 and 1989, marked by a much higher positive anomaly in 1988. This behavior of the basin, which is contrary to basins in the Sahel (Gal, 2017; Descroix, 2018), in India (Sahu**, 2023;** Mehta and Yadav, 2022**)** and even in Africa as a whole (IPCC, 2007), is linked to the return of rainfall to the basin in 1988. Indeed, 1988 coincided with the impoundment of the Nangbéto Dam installed in the north of the basin on the Mono River (Benin-Togo) to supply electricity to these two countries. This same year had already been identified in 2010 (Amoussou, 2010) and recently by R. T. Nakou et al. in 2022, where the authors showed that the dam contributed to the return of wet conditions in the basin from that date onward.

The two breakpoints in the lower Mono River valley in 1968 and 2007 show two periods of surplus rainfall, the first from 1960 to 1968 and the second from 2008 to 2018. This period of excess rainfall recorded between 1960 and 1968 is perfectly in line with the trend recorded in Africa in general (IPCC, 2007), where the rainfall trend across the continent was significantly upward. The year 2007, which marks the second break in rainfall in the basin, means that, compared with the reference period (1960 to 1968), there will be a 10% surplus between 2008 and 2018 (Table 2). This result seems to confirm the work of R. T. Nakou et al. in 2022, who noted an evolution of rainfall in the basin toward drastic conditions from 2009 onward. These authors linked the recurrent flooding in the basin in recent years to this return to drastic rainfall conditions from 2009. Indeed, according to these authors, with the trend toward extremely wet and intensely wet events increasing significantly in the basin, the nature of future floods and disasters in Benin's lower Mono River valley should be a cause for concern (Nakou et al., 2022). This behavior of the basin is akin to that of the basin of the Hathmati River, which is one of the most important tributaries in western India. Indeed, the analysis of the future scenario (2050s) by a representative concentration pathway (RCP4.5) over a reference period of 1980 to 2014 of the basins predicts an increase in precipitation to 1,015.54 mm from 936.91 mm (Shaikh et al., 2022). This represents an increase of approximately 8.45% in average precipitation. This is currently the same observation in several regions of the world, particularly in the United States and in southern and eastern Africa (Rigaud et al., 2019), in the Sahel (Rigaud et al., 2019), in Mahi (Pawar, 2023), Mahanadi (Sahu, 2023), western and eastern Rajasthan (Mehta and Yadav, 2021), India, Trinidad and Tobago (Perera et al., 2020) and St. Lucia (Leon and Oculi, 2023) in the West Indies…

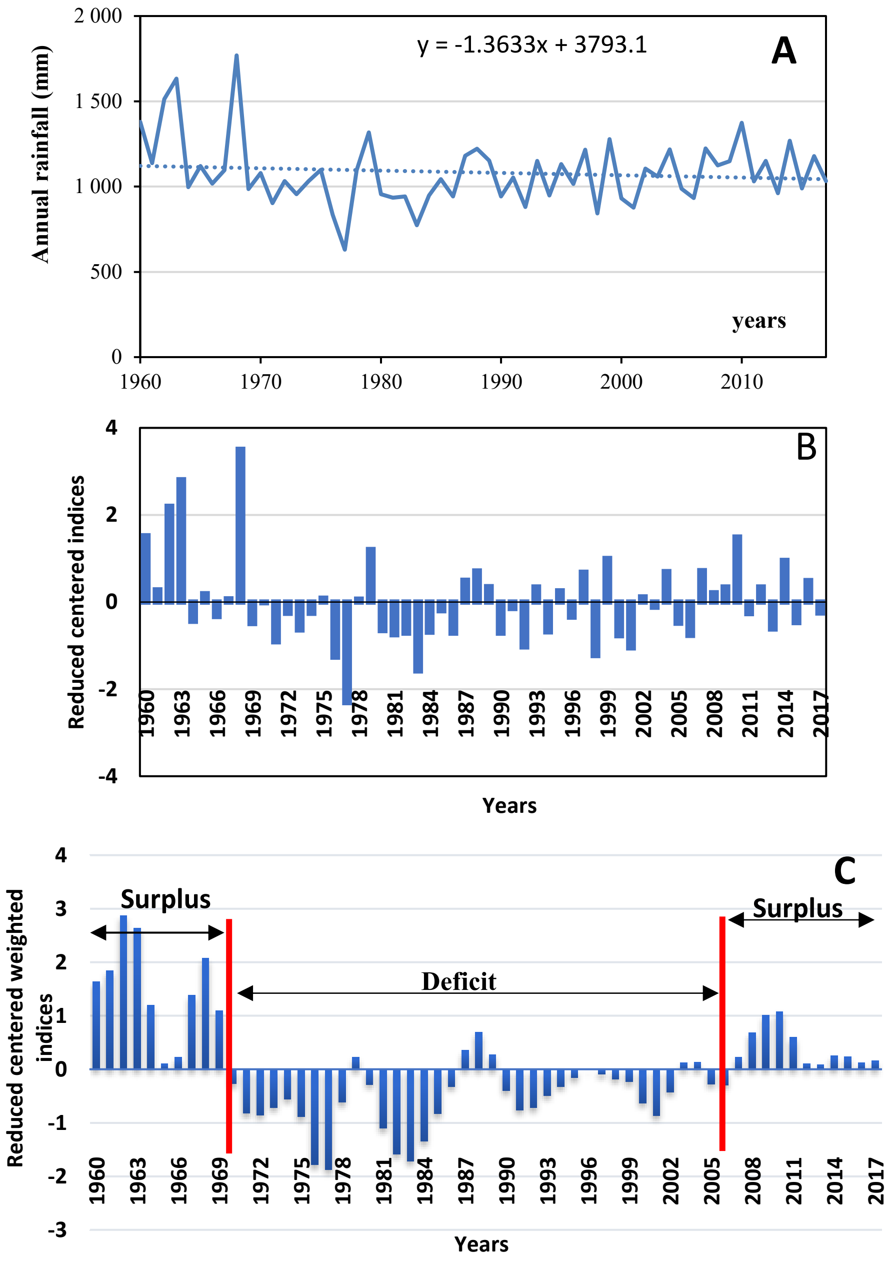


Figure 3: Variability and anomaly indices of precipitation variables in the Mono River basin from 1960 to 2018

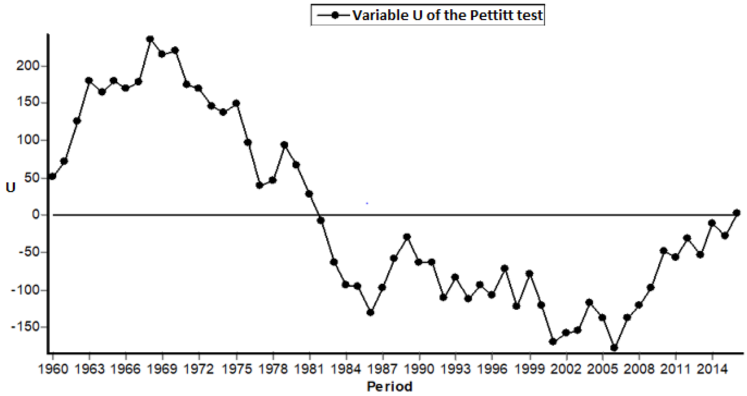


Figure 4: Evolution of the variable U in the Pettitt test

Table 1: Statistical tests on rainfall series, break years and impact after break

Observation of period	**1960 - 2018**	
P-average (mm)	1082	
Pettitt's test	-	
P- associated value	-	
Hubert's test	1968	2007
Scheff Significance	1%	1%
P-average (mm) before breakage	1295.67	1021.66
P-average (mm) after rupture	1021.66	1125.95
Impact of variability	-21%	10%

Study of the hydrological variability of the Mono River basin in Benin

The hydrological data used in this section come from the Athiémé hydrological station at the outlet of the Mono River located in the basin and cover the period from 1960 to 2018. Fig. 5 shows the variabilities (A) and weighted anomaly indices (B) of flow variables in the Mono River basin covering the same period from 1960 to 2018. It shows a significant (P value < 0.05) upward trend of 1.143 m3/s per year (Fig 5A.) for mean annual flows over the study period, with the highest flows observed between 1967 and 1969 and 1998 and 2018. Furthermore, stationarity tests detect 3 breakpoints in 1966, 1969 and 1997, which are shown in Fig 5 B obtained from equations 2, 3, 4, 5 and 6. This figure shows that the hydrological regime over the study period varied considerably. Thus, there are 4 subperiods, 1960-1966, 1967-1969, 1970-1997 and 1998-2018, with respective averages of 138.043, 306.933, 97.202 and 199.265 m^3/s. Compared with the 1960-1966 period, the 1967-1969 period had a flow surplus of 122%, the 1970-1997 period had a flow deficit of 70%, and the 1998-2018 period had a flow surplus of 112% (see Table 2). This 112% flow surplus between 1998 and 2018 explains the frequency of fluvial and slow flooding (Atiyè, 2017) by overflow with large magnitudes recorded in the basin in recent decades.

Since the 2000s, these floods have been frequent and have hit the basin hard, causing enormous damage and loss of life. The 2010 flood caused 46 deaths, the 2011 flood caused 25 deaths, 215 hospitalizations, and 46871 homeless people with enormous losses of crops (140287 ha) and animals (37339) (REBPC, 2011), the 2019 flood caused 46 deaths, 317 576 people affected, and 4899,1 ha destroyed (REBPC, 2019), and the 2020 flood caused 6 deaths and 7000 displaced people (REBPC, 2020). This damage caused by flooding in the basin already confirms the hypothesis of Nakou et al. in 2022 and those from Bong et al. (2023) in Malaysia, which predisposes the basin to intense and extremely rare rainfall events with a very high degree of vulnerability to climatic disasters. The same forecasts are in progress for the upper Tapi basin (Malani and Yadav, 2022) in India, for the Niger River basin (Yarou, 2019) in northern Benin, Saint Lucia (Leon and Oculi, 2022, 2023) in the West Indies, and in the sub-Saharan regions of Africa, where the vulnerability of populations to climate change has increased with the rise in sea level and rainfall anomalies, which are increasing in frequency and intensity, profoundly modifying the geography of the region (IMF, 2020).

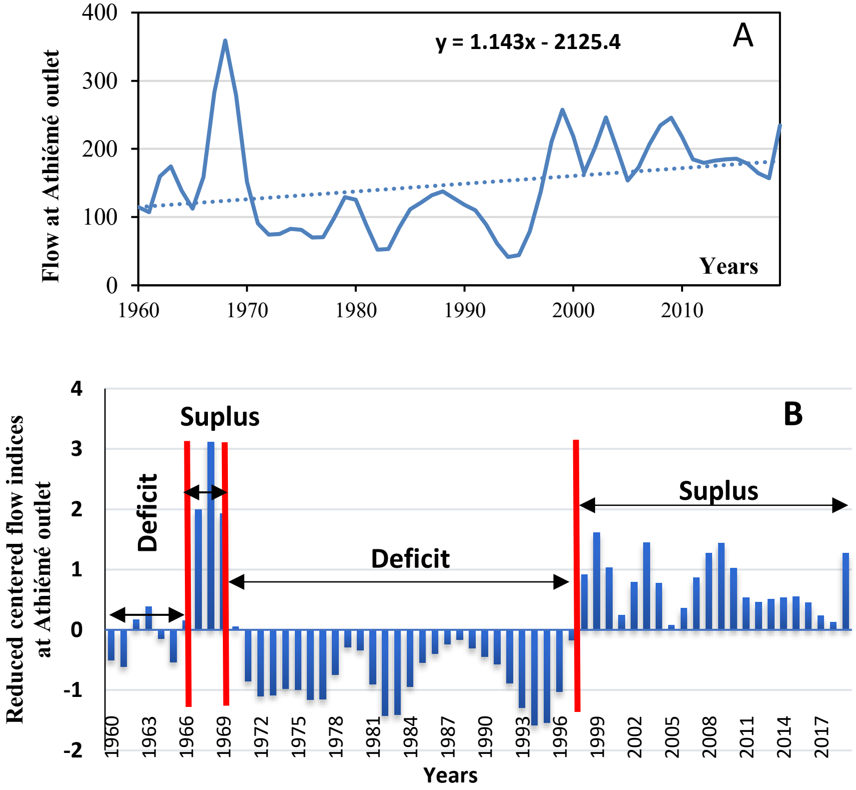


Figure 5: Variability and weighted anomaly indices of flow variables in the Mono River basin from 1960 to 2018

Table 2: Statistical tests, break years and postbreak impact in hydrological series

Observation of period	1960 à 2018		
P-average (mm)	1082	-	
Pettitt's test	-	-	1997
P- associated value	-	-	$5\ 10^{-6}$
Hubert's test	1966	1969	1997
Scheff Significance	1%	1%	1%
P-average (mm) before breakage	138.043	306.933	94.204
P-average (mm) after rupture	306.933	94.204	199.264
Impact of variability	122%	-70%	112%

Hydrological balance of the study basin according to break periods

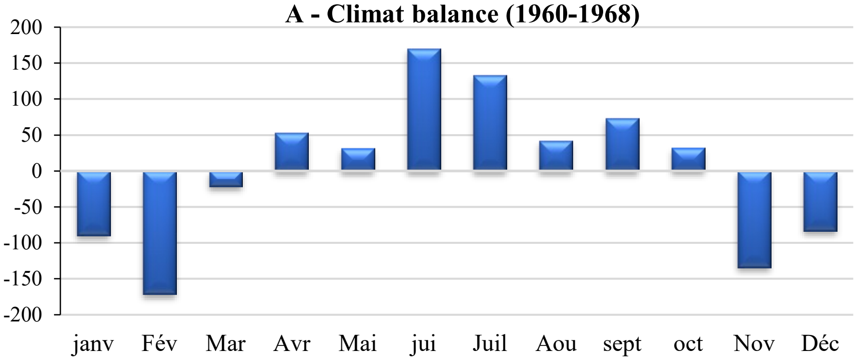
Analysis of Fig. 6 shows that the climatic balance (difference between the sum of rainfall and potential evapotranspiration) is positive in April, May, June, July, August, September and October, with a peak in June for all study periods. The deficit months are November, December, January, February and March, with a peak in February for all study periods, which favors aquifer recharge in Benin's lower Mono River valley. This peak month belongs to the basin's main rainy season, which begins in March and ends in June.

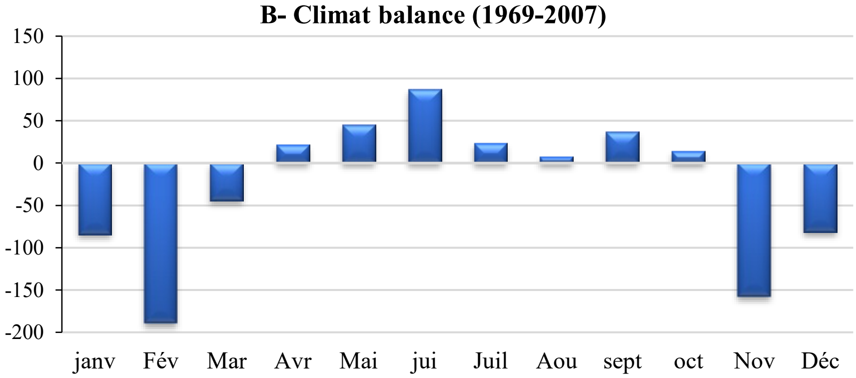
A comparison of annual precipitation and annual potential evapotranspiration (PTE) shows a deficit in the hydrological balance for all study periods (Table 3). A comparison of infiltration rates obtained from the water balance equation (Eq. 7) shows the impact of changes in rainfall patterns in Benin's lower Mono River valley on groundwater recharge in the basin. This infiltration rate, which represents the percentage of water likely to reach the underground reservoirs in Benin's lower Mono River valley, is highly variable depending on the period. It increases from 12.73% before the first rupture to 1.57% after the first rupture and 5.71% after the second rupture. A comparison of these rates provides an idea of the impact of rainfall changes on aquifer recharge in this part of the basin.

The decline in groundwater resources in the basin between 1969 and 2007 is estimated at 84.25%, confirming the results of E. Amoussou in 2010 on the slopes of the Mono-Ahémé-Couffo fluvial-lagoon complex. By analyzing flow variability and sediment dynamics in the Mono-Ahémé-Couffo watershed over the period 1961-2000 in an integrated water resources management (IWRM) context, the author showed that rainfall deficits in the 1970s and 1980s multiplied flow deficits by a factor of 4, resulting in recharge deficits in the complex.

This period (1969-2007), marked by a very pronounced hydrological deficit, was due to the break in the basin's rainfall regime in 1968. This change in the rainfall pattern in the lower Mono River valley in Benin resulted in a 21% rainfall deficit (Table 1), which generated 87.64% of the recharge deficit. In Côte d'Ivoire, work by B. T. A Goula et al. in 2006 showed that the hydrological impact of rainfall scarcity was 2 times more intense in the N'zi basin: 49% in 1969-2004 versus 27% in the N'zo basin in 1970-1993. This phenomenon, which seems to be widespread during this period in all Sudano-Guinean basins where the drop in runoff coefficients is probably linked to a reduction in groundwater resources, is a consequence of the droughts of the 1970s and 1980s that hit the region (IPCC, 2007), causing many rivers and reservoirs to dry up or run off less. However, some basins in the Sahelian zone have experienced different and paradoxical hydrological behaviors (Gal, 2017; Descroix, 2018). In these cases, it seems that the evolution of vegetation interfered with climatic variability. Thus, vegetation degradation and the increase in cultivated areas following drought and anthropic pressure have led to an increase in runoff coefficients in the Sahel, potentially resulting in an increase in runoff (Mahé, 2005).

The increase in the infiltration rate after the second break (2008-2018) was due to the return to wet conditions in the lower river valley. This return to wet conditions was clear from 2007, the date of the second fault. This behavior of the basin between 2008 and 2018 has been general in West Africa since the mid-1990s, when a recovery in rainfall was observed (Ozer, 2009; Ozer, 2017; Sara 2022). This increase in underground resources in the basin, however slight, contrasts with the realities on the ground. In fact, some of the basin's catchment structures (wells and boreholes), which in the past had a permanent regime, now have a temporary regime.





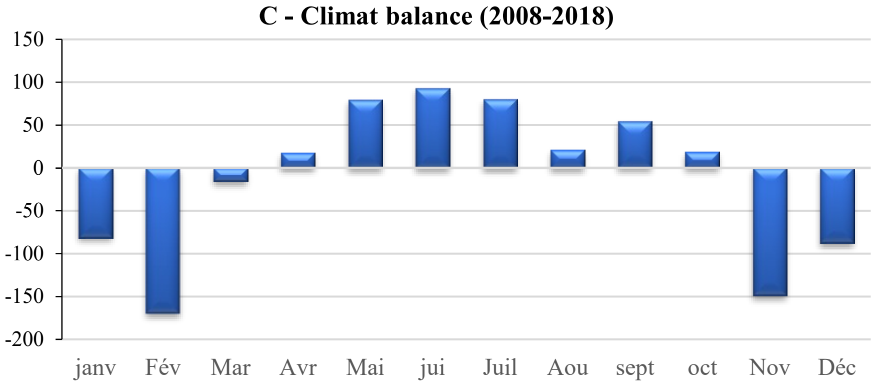


Figure 6: Climatic balance of the lower Mono River valley in Benin according to break periods

Table 3: Summary of water balance results for the basin

Period	1960-1968	1969-2007	2008-2020
Average rainfall	1167.35 mm	868.64 mm	1024.60 mm
Potential Evapotranspiration (ETP)	1237.5 mm	1257.9 mm	1269.0 mm
Runoff déficed(D)	907.95 mm	772.49 mm	868.11 mm
Runoff (R)	110.85 mm	82.49 mm	97.30 mm
Infiltrated water (I)	148.55 mm	13.66 mm	59.19 mm
Infiltrated rate	12.73%	1.57%	5.78%

CONCLUSION

This study made it possible to highlight the existence of climatic variability in the lower valley of the Mono River in Benin and to understand its impact on water resources between 1960 and 2018. The approaches used identified two point ruptures (1968 and 2007) in the rainfall regime of the basin, which show three subperiods, 1960-1968, 1969-2007 and 2008-2018, with averages of 1295.667 mm, 1021.6585 mm and 1125.9485 mm, respectively. It appears that the study area has three periods of interannual variability over the study period, two of which are wet (1960-1968; 2008-2018) and a deficit period from 1969-2007. The basin is known compared to the subperiod from 1960 to 1968, a dry period of 21% between 1969 and 2007 and a wet period of 10% between 2008 and 2018. The hydrological regime of the basin experienced three ruptures in 1966, 1969 and 1997. The hydrological balance carried out over each period of the rainfall regime proved to be in deficit, with a recharge rate of 12.73% between 1960-1968, 1.57% in 1969-2007 and 5.78% from 2008-2018. The comparison of these rates over the basin gives an idea of the impact of climate variability on the underground resources of the basin. Even if the infiltration rate in the underground reservoirs of the basin between 2008-2018 is 4.21% more than that of the period of 1960-1968, this result contrasts with the realities on the ground where it is noticed today, a temporary regime on certain catchment structures (wells and boreholes) that previously had a permanent regime. This situation prevailing in the basin requires further reflection.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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