

Analysis of Climate Variability and Its Influence on the Hydrological Response of the Catchment Area of Kadey (East Cameroon)

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Abstract

Register in the framework of the International Program of Research on Water Resources Management and Protection of Ecosystems, the Congo basin in which lies the catchment area of the Kadey (2647 km²) was selected to better assess the impact climate variability on the water surface in the perspective of supply drinking water both in the rainy season and in periods of low water. Based on new data from rainfall and flow rates obtained in the last fifteen years (1998-2013), the major trends in time series and the scope of the “drought” were identified. The historical rainfall in the basin is characterized by two major ruptures rainfall in 1969 and 1999. These have generated an order deficit of 14% respectively and an excess of nearly 19%. These phenomena also affected the recurrence of cumulative rainfall throughout the Kadey basin. Here, the hydrological response to excess rainfall is over 100%. However, it appears that over the period 1970-2012, the number of years that has undergone a “severe drought” is to play down.

Keywords

Catchment Area of Kadey, Climate Variability, Surface Water, Hydrological Response

1. Introduction

Cameroon and Central Africa under mousson regime, is a vast complex where the climate is governed by the movement of the Atlantic mousson. This part of Africa is hit in recent decades by a more or less severe drought as the climate is equatorial, tropical humid and semi-arid [1]-[3]. This decrease in current rainfall since the beginning of the 70s seems to be the consequence of strong climate variability because of a likely disruption of the West African mousson [3]. It is characterized by a decrease of about 15% to 20% of the rainfall and an even greater decline in stream flow [4] [5].

However, this background of general decline hydroclimatic is upset for example by increasing the speed of the Oubangui River (Central African Republic) since 1970 despite a significant rainfall deficit [5] [6]. This hydrological paradox is also observed in Gabon and Central African Republic in equatorial climate through an increase in groundwater level over the last 50 years around small endorheic ponds and rivers [5] [7].

The catchment area of Kadey is a sub-watershed of the Congo drained by the river with many tributaries Kadey as Boumbe II, Mama, Kudu and Doume rivers. The aim is to better characterize climate variability through rainfall across the basin and assess its hydrological response from the flow variations at the outlet.

On Presentation of the Study Area

The catchment area of Kadey (2 647 km²) is located in Eastern Cameroon, between longitudes 14°29'E and 14°45'E and the latitudes 4°12'N and 4°36'N (Figure 1). The basin is located in the equatorial climate transition upstream from the part of the basin located south of the Sanaga. As for the entire Congo Basin, annual average rainfall is 1428.9 mm between 1960s and 2013s. The rainfall pattern has four seasons marking the equatorial influence. The distribution of seasons varies following stations. However, the aspect “camel’s back” characterizes all stations of the Sangha Basin, with two maxima and two minima well marked. The second maxima is always most powerful. The highest temperatures are observed between March and April and are respectively 25.4°C Batouri, 25.9°C to 26°C and Dem Bertoua. In terms of the lowest temperatures, they correspond to the months of July and August, with 23°C in Batouri, Bertoua 23.4°C and 23.9°C to Dem. The hydrographic network of the basin narrows upstream downstream. The relief consists of upstream basin plateaus, plains in the middle and downstream lowlands whose altitude varies between 600 m and average 880 m. However, there are isolated ancient massifs whose peaks reach around 927 m. The geology of the watershed consists of base for the most part [8]. The population is predominantly rural and relatively dense. The main economic activity remains artisanal gold mining although agriculture remains the main activity in the whole of Congo.

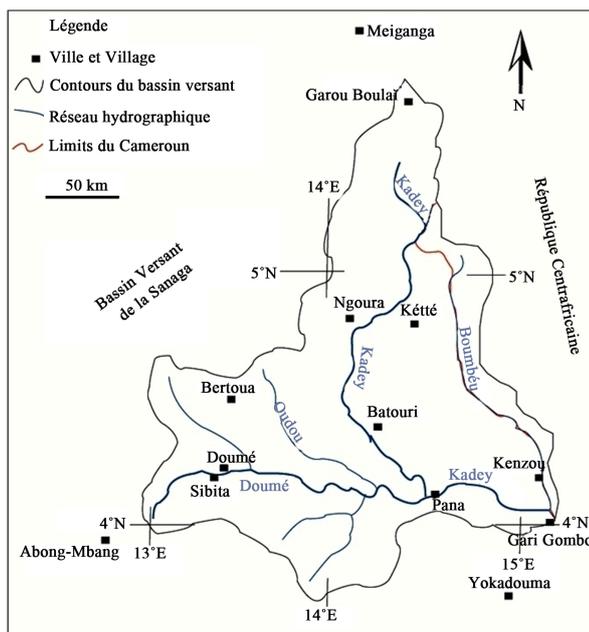


Figure 1. Location of catchment area of Kadey.

2. Data and Methods

2.1. Data Acquisition

Rainfall data come from the service of the Agency's documentation for the Safety of Air Navigation in Africa and Madagascar (ASCENA) at the airport of Bertoua and the National Meteorology of Cameroon. They are recorded from 5 rainfall stations distributed over the basin and whose observations sizes vary from one station to another. The Longest chronicle (1969-2014) is recorded in the rainfall station in Bertoua, located in the North East of the basin. This long series will better appreciate the long-term rainfall variability.

Hydrometrics data are from the 1972-2013 period stations Bertoua and Batouri, extracted from the database of the hydrological research centre of Cameroon and field descents.

2.2. Methods

2.2.1. Calculations of Rainfall and Hydrometrics Indices

In time series, rainfall and hydrometric is evidence to identify the major trends. They are calculated by the method of weighted moving average filter or low-pass Hanning 2nd order.

To do this, we first proceed to data filtering to remove seasonal variations using the non-recursive low-pass filter Hanning 2nd order (it is a application of weighted moving averages). The implementation and determination of this filter is carried out by means of mathematical equations that permit to estimate each term in the series as follows:

$$x(t) = 0.06x(t-2) + 0.20x(t-1) + 0.38x(t) + 0.25x(t+1) + 0.06x(t+2) \quad (1)$$

$$\text{with: } 3 \leq t \leq (n-2)$$

where: $x(t)$ is the total rainfall weighted for term t , $x(t-2)$ and $x(t-1)$ are observed total of two out above the term t immediately, $x(t+2)$ and $x(t+1)$ are the observed total of two terms that follows the term t immediately.

The weighted total of the first two [$x(1)$, $x(2)$] and the last two [$x(n-1)$, $x(n)$] terms of the series are determined by the following expressions (n being the size series):

$$\begin{aligned} x_{(1)} &= 0.54x_{(1)} + 0.46x_{(2)} \\ x_{(2)} &= 0.25x_{(1)} + 0.50x_{(2)} + 0.25x_{(3)} \\ x_{(n-1)} &= 0.25x_{(n-2)} + 0.50x_{(n-1)} + 0.25x_{(n)} \\ x_{(n)} &= 0.54x_{(n)} + 0.46x_{(n-1)} \end{aligned} \quad (2)$$

To better visualize the periods of surplus and deficit in inter annual, the calculated moving averages have been centered and reduced from the following formula:

$$Vcr = \frac{(P - \bar{P})}{\sigma} \quad (3)$$

With: Vcr is reduced centered variable (rainfall and hydrometric Index according to the studied variable), P is the sum of the variable over a given period t , \bar{P} is the average of the time series over the period of study and σ is the standard deviation of the series on the study period.

2.2.2. Ruptures Detection Tests in Time Series

In this study, breaks tests permits to determine the various pivotal years of climate change in a watershed. Their roles come in supplement to rainfall and hydrometric evidence collected at weather stations. The existence of abrupt changes in hydroclimatic series is a possible cause of the heterogeneity of these series [9]-[12].

These tests are essentially based on the Bayesian method of Lee and Heghinian, Pettitt and segmentation Hubert [13] [14]. Tests Lee and Heghinian and Pettitt designed to detect breakage maximum while segmentation Hubert allows in turn to identify more if they exist in a time series data [15]-[17]. Their application is carried out using the KhronoStat 1.01 software developed by the French Institute of Research for Development (IRD).

2.2.3. Estimated Periods of Rains Back around Breaks

With HYFRAN 1.1 software developed by the Canadian Institute (INRS-ETE) and used here, we did a fre-

quency analysis of rainfall totals on each break period to be identified. The goal is to determine any variation in the return period of a P rain due to the rupture. The purpose of this calculation is to better assess the impact of climate variability on the choice of the rains (and flows) project in the design of hydraulic structures.

2.2.4. Determination of the Magnitude Drought

1) SPI and ranges of values meaning

In hydroclimatology, standard ranges of SPI index values used to assess the extent of moisture (or dryness) for each year of the time series. After this operation, it is possible to determine the number of years in line SPI and the corresponding meanings in terms of scale of the climate phenomenon (**Table 1**) from the following equation:

$$A_i = \left(\frac{ni}{N} \right) \tag{4}$$

A_i is the percentage of the years concerned by the class i (**Table 1**), ni is the number of years of class i and N , the total number of years over the study period.

2) Deficit (or excess) rainfall and hydrometric

In the catchment area of the Kadey as in the whole of the Congo Basin, the dominant phenomenon throughout the time series is finally obtained for the SPI range for which we records the highest percentage.

Here, the magnitude of drought can also be assessed from the deficit calculation. For hydroclimatic for which variables time series presents a break, this method specifies the percentage change in the average around the break date [18]-[21]. This deficit is obtained by the following formula:

$$D = \left[\left(\frac{x_j}{x_i} \right) - 1 \right] \times 100 \tag{5}$$

D is the hydrometric or rainfall deficit, x_i is the average of the period before the break, x_j average for the period after the break.

3. Results and Discussion

3.1. Hydrometric and Rainfall Indices

Changing rainfall indices between 1960 and 2012 suggests three possible ruptures. Before the first break that marks the end of the 1960s, there have been positive rainfall indices. This is typical annual rainfall above the average interannual due to an excess rainfall regime during this period. For the 1970-1992 sequence, almost 90% of the years concerned correspond to negative rainfall and hydrometric index reflecting a deficit rainfall pattern (**Figure 2**). A return to surplus occurs years after this deficit sequence in deficit until 2000. The decade 2010 is not yet complete, is characterized by alternating positive and negative indices. Subsequent monitoring of the rest of the series will better identify the trend of this decade.

3.2. Tests of Rainfall and Hydrometric Breaks

In deciding on the number of disruptions in rainfall to retain, the application of tests and Lee Heghinian, Pettitt (**Table 2**) have permitted to detect a single break in 1969 while the segmentation Hubert has detected one in

Table 1. Different classes indices SPI and their meanings.

N° of Classes	Classes SPI	Interpretation
1	SPI > 2	Humidity extreme
2	1 < SPI < 2	High humidity
3	0 < SPI < 1	Moderate humidity
4	-1 < SPI < 0	Moderate drought
5	-2 < SPI < -1	With drought
6	SPI < -2	Extreme drought

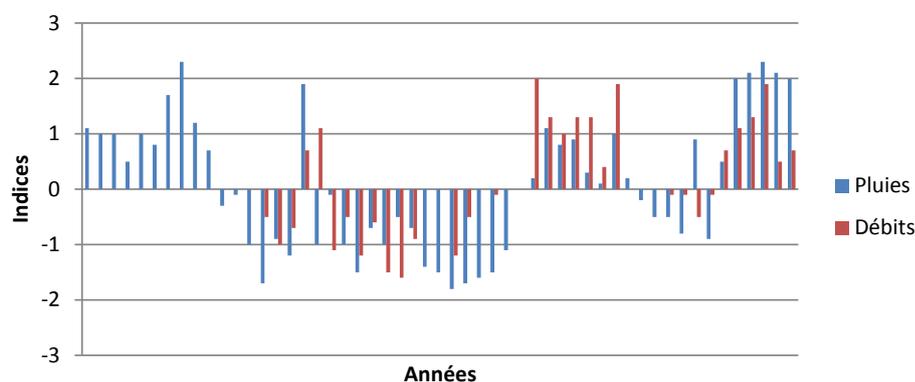


Figure 2. Indices of rainfall and hydrometric 1960-2013.

Table 2. Results of tests applied to breaking rainfall and hydrometric data.

	Tests breaks	Year average or break	Period before the first break (mm)	Average speed after the first break (mm)	Average speed after the second break (mm)
Rainfall (1960-2012)	Lee e and Heghinian	1969	1405	1117	
	Pettitt	1969	1405	1117	
	Segmentation Hubert	[1960-1969] [1970-1991] [1992-2012]	1405	1034	1263
Hydrometry (1972-2012)	Lee and Heghinian	1988	27	59	
	Pettitt	1992	31	75	
	Segmentation Hubert	[1992-2012] [1993-2012]	31	75	

1969 and another in 1992 in line with the indices previously observed. Ndam *et al.* (2016) in their study of the Sanaga and Mfochivé (2011) on the catchment area of So'o, observed rainfall ruptures between the years 1968 and 1970. This is also the case Kpoumié and al. (2009) on the Sangha basin. This breakdown shows that the catchment area of Kadey fits well in general changes in rainfall patterns observed in the late 1960s in Central Africa in general and in the Congo Basin in particular.

Breaks tests applied to hydrometric data (**Table 2**) confirmed a single break on the two observed from rainfall indices. That of Lee and Heghinian detected a break in 1988 while those of Pettitt and Hubert confirmed that of 1992. After the breaks as well as gauging rainfall observed in 1969 by Lebel and Vischel (2005); Servat *et al.* (1995); Goula *et al.* (2006) and by Mahe *et al.* (2000) in 1991, the 1988 break seems specific to data quality and tests used. On three tests applied, that of Lee and Heghinian is the only to detect.

3.3. Variability of Recurrence Rains around Breaks

The annual rainfall totals are, in general, the more important they are rare (**Figure 3**). So we can see that before the break of 1970, annual rainfall less than 1350 mm showed a recurrence of at least 1 time every 5 years (**Figure 3(a)**). Beyond this value, precisely from 1420 mm, annual totals have long return periods (20 years) to very long (100 years). During the period 1970-1992, for the same return periods, annual rainfall has significantly decreased accumulation (**Figure 3(b)**). This is the case when there is a return of 3-year period before 1970. At this level, the cumulative rainfall of 1300 mm became centennial.

In short, we can say that the climate change that has occurred during the 1970s has had the impact of a variation of the recurrence of rainfall annually until 1992 on the whole basin. However, at the beginning of the 90s and especially after 1992, it is noted that the recurrence of annual rainfall has shifted to the behavior observed during the decade 60 (**Figure 3(c)**). This new trend reflects a rainfall recovery that seems to break the long “drought” highlighted by many authors [20] [22]-[25].

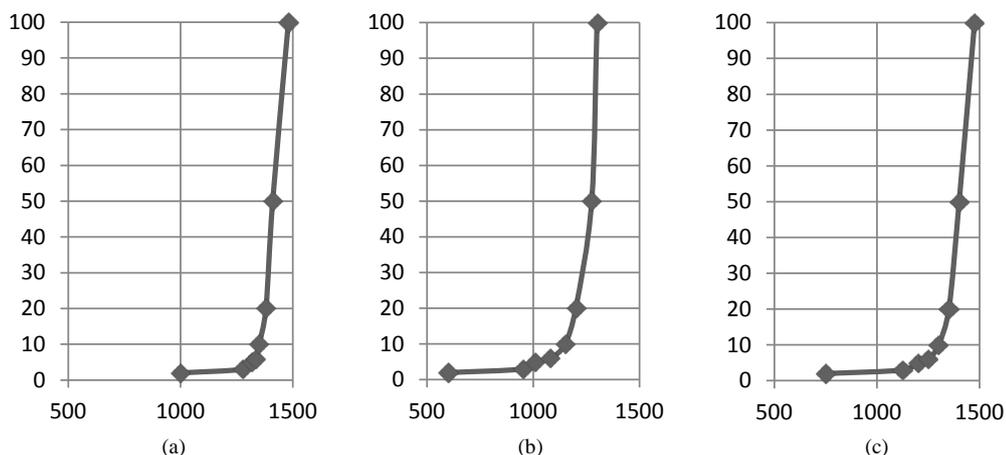


Figure 3. Impact of disruptions on the recurrence of rainfall annual rainfall; (a) period of 1960-1969, (b) 1970 to 1991 period and (c) period of 1992-2013.

3.4. Extent of Drought

1) SPI and ranges of values meaning

Fluctuating hydro data observed on the Kadey basin materialized by alternating wet and dry years as shown by the evolution of SPI indices. In this way, on the basis of these indices expressed by rainfall data for the study period (1960-2013), 25% of years of observation have suffered a moderate drought and only 11% correspond to a severe drought plan. In contrast, we note that over the same period, 47% of years running under a moderate moisture regime and the remaining 17% correspond to a moisture content ranging from high to extreme (**Table 3**). On the pelvis, SPI expressed from flows are characteristic of a “drought” (42%) from high (15%) to moderate (27%). The 58% of the remaining years undergoes moisture to varying degrees (**Table 3**).

Out of all the two hydroclimatical parameters, the “drought” has a generally moderate nature. However, a considerable number of years have suffered very heavy periods “drought”, this number also appears higher for the flow.

2) Deficit (or excess) rainfall and hydrometric

Observations, we note: before 1970, the average annual rainfall is 1477 mm. It increased to 1 268 mm between 1970 and 1992. This corresponds to a deficit of about 14% which is in the same range as that observed elsewhere in the other basins in South Cameroon [26]-[30]. After 1992, the trend has shifted to an excess of about 18, 5% until 2008 and 20% in 2012. In contrast to rainfall, hydrometric series is truncated because it starts in 1972 and ends more or less between 2004 and 2005.

A break is observed in 1990 by the test Lee, but this is not confirmed by the two other rather that hold 1992 agreement with the rainfall. This rupture generated a gain of over 108% runoff. We can therefore infer that excess rainfall for 18, 5% - 20% or about 19%, you get a 108% surge in flows is 5, 5 times the rainfall surplus (**Table 4**). Everything resulting nonlinearity between rain and flow in the watershed Kadey as is the case in Equatorial area general and Southern Cameroon in particular [29]-[31].

4. Conclusions

The main purpose of this study was to better explain and understand climate variability to better assess its impact on surface runoff. Indeed, from 1960 to 2012, the climatic variability on watershed Kadey was characterized by two major breaks rainfall occurred in 1969 and 1992. The first break, characteristic of a scheme deficit has caused the loss of rainfall order of 14% and a scarcity of annual rains becoming stronger. The second rupture generated excess rainfall nearly 19% and an increase in the recurrence of heavy rains, reflecting a return to surplus trend. The hydrological response to this rainfall amount is over 100%. In terms of number of years, drought nevertheless has a moderate nature. The present work is to highlight the non-linearity of the relationship between rainfall and flow in the equatorial areas.

In a medium- and maybe even in the short term, a more detailed analysis of the contribution of underground tanks with flow production process will better understand this relationship.

Table 3. Extent of drought (and moisture) between 1960-2013.

Variables	SPI ranges	Interpretation	% Years
Rainfall (1960-2013)	SPI > 2	Humidity extreme	4
	1 < SPI < 2	High humidity	13
	0 < SPI < 1	Moderate humidity	47
	-1 < SPI < 0	Moderate drought	25
	-2 < SPI < -1	With drought	11
Hydrometry (1972-2013)	SPI > 2	Humidity extreme	5
	1 < SPI < 2	High humidity	29
	0 < SPI < 1	Moderate humidity	24
	-1 < SPI < 0	Moderate drought	27
	-2 < SPI < -1	With drought	15

Table 4. Deficits (excess) rainfall and hydrometric around breaking years.

	Average or break year period	Before the first break (mm)	Average speed after the first break (mm)	Average speed after the second break (mm)	Deficit/surplus (%)
Rainfall (1960-2013)	1969	1405	1117		-20%
	1969	1405	1117		-20%
	[1960-1969]	1405			
	[1970-1991]		1034		-26%
	[1992-2013]			1263	+22%
Hydrometry (1972-2013)	1988	27	59		+118%
	1992	31	75		+141%
	[1972-1992]	31			
	[1993-2013]		75		+141%

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