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Analysis of Hydro-Climatical Variability in the Mo Basin in Togo

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Abstract

Climate changes are affecting water resources around the world and the Mo Basin (MB) in Togo is no exception to this observation. This study aims at analyzing the influence of hydro-climatical data in the Mo Basin. To achieve this, Pettit's stationarity break tests, Hubert's segmentation, Nicholson's [1] reduced centered index, Lamb [2] and flow coefficients have been applied. In addition, temperature, precipitation, evapotranspiration, relative humidity and discharge data from 1961 to 2018 have been used for this purpose. While rainfall is decreasing despite an increase of 22.8% at the Fazao station and 2.8% at Sotouboua station, the flow coefficients evolve synchronously with the precipitation data and show a strong link between both parameters. The climatic balance sheet is positive six months in the year (May to October), throughout the period of observation (1961-2018). Only 1962 and 1963 recorded an annual rainfall greater than the annual evapotranspiration. The other years undergo a climatic drought, increasingly pronounced, which strongly impacts the hydrology of rivers. This has a strong impact on water resources and food security and resources of the Fazao-Malfakassa reserve in the region.

Keywords

Climate Variability, Hydro-Climatic Balance, Mo Basin, Togo

1. Introduction

Water is an indispensable resource for economic growth and the improvement of people's well-being. When it is lacking, it is a source of penury and can lead to conflicts. On the other hand, when it is overabundant, it causes devastating floods. Its multifaceted character is dependent on climatic variables (rainfall, temperature, evapotranspiration, relative humidity, etc.). Therefore, its study is crucial for the management and planning of water resources [3].

The studies of IPCC [4] and those of many authors [5]-[10] attest that West Africa is one of the most vulnerable regions in the world to hydro-climatic variability marked by recurrent droughts inducing a pronounced drop in rainfall, that affect river runoff and piezometric levels. The hydro-climatic variability observed since the seventies has direct or indirect impacts on the water cycle and the hydrological regimes of the watersheds.

Togo, like other West African countries has the watersheds that are increasingly threatened by hydro-climatic variability. However, these sectors are very attractive in terms of the resources they contain and many populations benefit from the socio-economic advantages that they offer. The hydro-climatic variability observed in the West African sub-region has significant consequences in Togo [10] [11] [12], particularly in the Mo Basin in the central-western part of the country, where the spatio-temporal variability of hydro-climatic parameters conditions the availability of water resources and all anthropic activities. This study aims at analyzing the hydro-climatical variability in the Mo Basin.

2. Study Area

The Mo Basin is a sub-basin of the Oti River Basin which is of the sub-basin of the Volta River basin shared by six countries namely Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali and Togo. Located in the center-west of Togo, the Mo Basin straddles the regions of Kara and Central and corresponds to the transition zone between the Volta and the chain of the Dahomeyides. It extends from 8˚27'20" to 9˚37'20" North latitude and from 0˚30'20" to 1˚00'20" East longitude like presented by **Figure 1**.

The Mo basin stretches over 5512 Km^2, that is. 9.7% of the national territory. The Mo is 160 km long up to its outlet in the Oti river. It has its source in the Alédjo-Kadara Mountains and has an average flow of 20 m^3/s and a maximum flow of 80 m^3/s [13]. It serves as a border between Togo and Ghana for more than 37 km. The geological formations are sedimentary in the Volta Basin and crystallophyllous on the Dahomeyen plinthe. They correspond to the Oti plain in the west, dotted with sandstone hills of 500 m in altitude, and to the Togo Mountains in the East, which present vivid reliefs of 750 to 850 m in altitude, such as the Fazao and Alédjo-Kadara Mountains.

The relief of the Mo basin is deeply dissected by rivers that give rise to deep valleys individualizing hills and mountains, among which the Fazao-Malfakassa dominates in the southeast and the Tchaoudjo massif in the northeast. The Mo River drains a small plain that opens to the southeast at Ghana border.

The climate is of a tropical type, Sudano-Guinean, with two seasons: a dry season (November to April) and a rainy season (May to October). Average annual rainfall varies from 1100 to 1600 mm depending on the year, with a norm (1988-2018) of 1300 mm in the stations of Sotouboua and Sokodé. **Figure 2** shows that the maximum rainfall is recorded in August or shifted to September

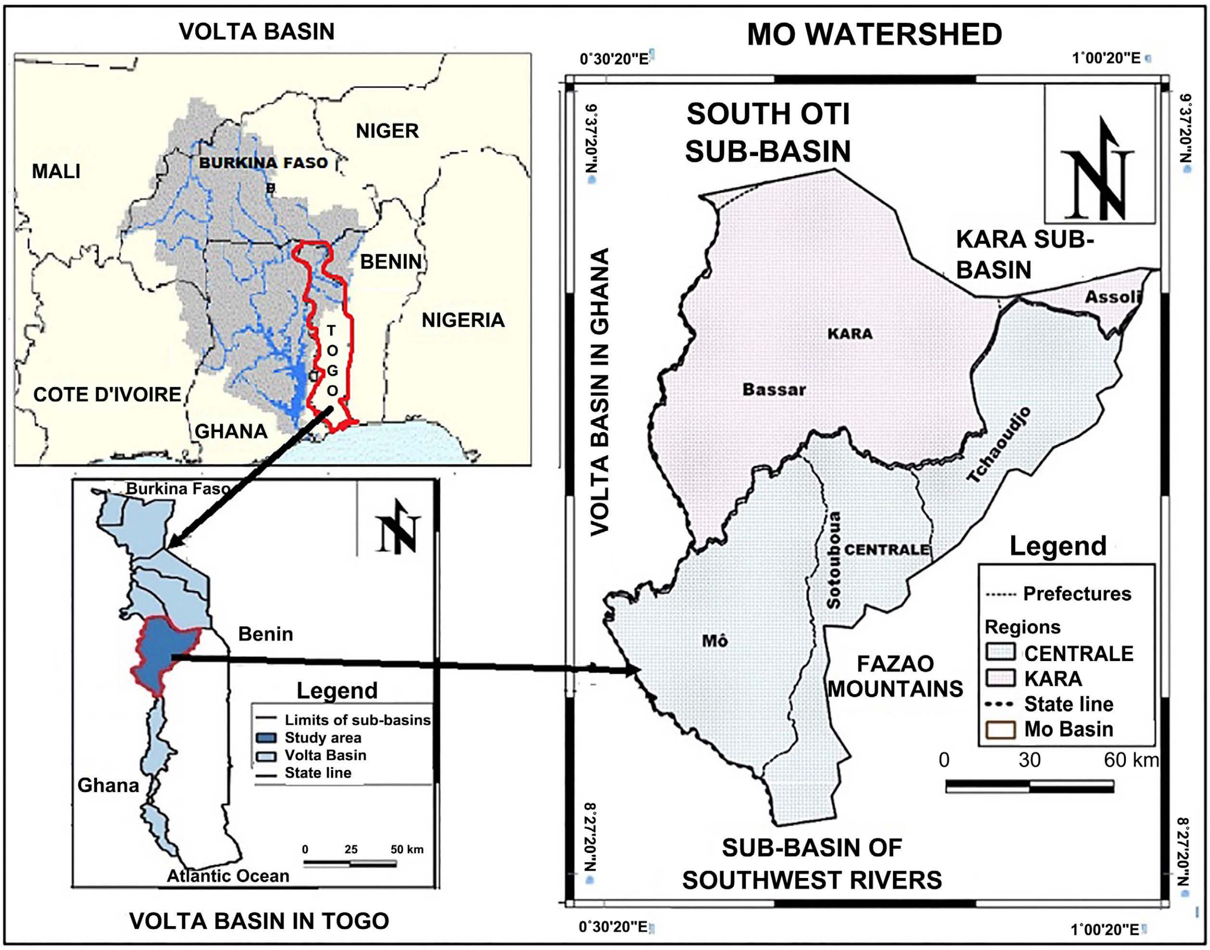

Figure 1. The Mo watershed.

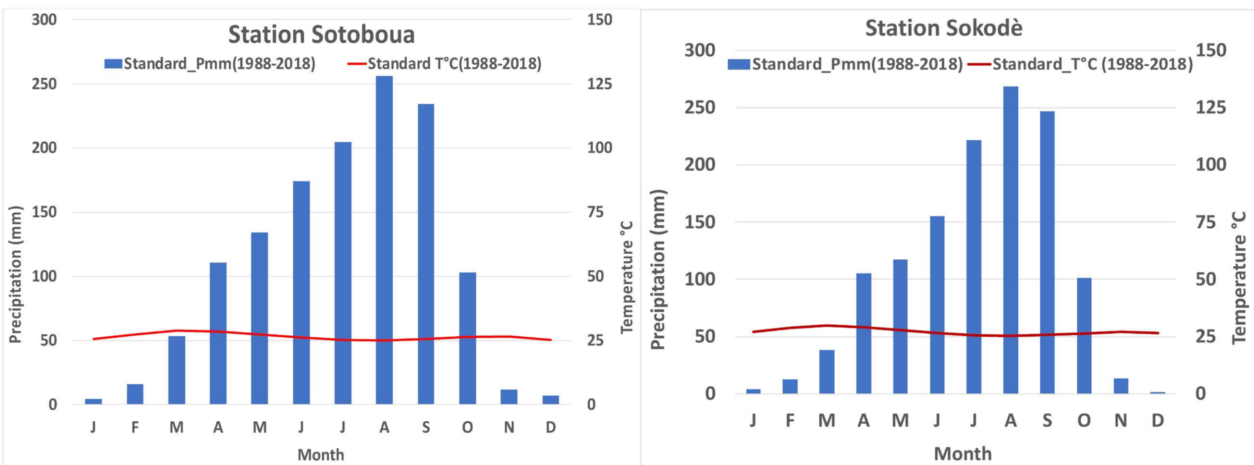

Figure 2. Ombrothermic curve of the Sotouboua and Sokodè station (1988-2018).

and the average temperatures in the basin are around 25˚C to 26˚C, with the extrema temperatures recorded in March (28˚C to 30˚C), while the lowest are recorded in August (24˚C to 25˚C).

The vegetation of the Mo basin is consisted of wooded savannah and grassy grassland, with reserves of dry and open forest often threatened and disturbed by bush fires and human activities, gallery forests along rivers and depressions. The areas around the rivers also correspond to the Fazao-Malfakassa National Park.

3. Data and Methods

Climatic and hydrological data have been used for this study. The longer climate data are 57 years; while the hydrological data are much shorter and are of unequal length, so that only the station with the longest data observation will be taken into account, *i.e.* 28 years of observation.

3.1. The Data

The necessary data for the study have been collected at the National Meteorology Department (NMD) over the period 1988-2018 for climatic data of Fazao, Sokodè and Sotouboua stations; regarding rainfall, temperature, evapotranspiration and relative humidity. The hydrometric data have been obtained from the Ministry of Rural Equipment and Hydraulic Village and consist of flow rates. These are the monthly data from the stations of Sokodé-Bassar (1976-1989), Kama-Bassar (1962-1990) on the two main tributaries of the river and Boulougou (1971-1991 and 2011-2018) on Mo river. Unfortunately, the hydrological data is not recent and stops in 1990.

3.2. Methods

Statistical methods like the index of Nicholson and Lamb were used to analyze rainfall data. The trend and break detection tests (Buishand test, Pettitt test and Hubert's segmentation) have been used for highlighting the different breaks with respect to the sequential averages. The Drought Index (DI) is used to define the level of dryness of the basin and the hydrological variation is analyzed through the climatic balance sheet and the rainfall/flow relationship.

Indeed, the index of Nicholson and Lamb has allowed to analyze climatic or hydro-climatic trends and to differentiate dry periods, wet periods and normal periods. This index is expressed by the following formula:

$$\text{RCI} = \frac{\text{Xi} - \text{Xm}}{\sigma(x)}$$

I = standardized anomaly index; Xi = mean value of the variable considered; Xm = mean of the series; σ = standard deviation of the series.

$$\sigma = \frac{\sum(\text{Xi} - \text{Xm})^2}{n}$$

n = the number of data.

This indice has been used by many west African researchers like [7] [8] [12] [14] to highlight climatic parameters variability.

The software KhronoStat 1.01 developed by the French Institute of Research for Development (IRD) was used to detect breaks. It allows the application of different tests, in particular, the Buishand statistical test and Hubert's segmentation which are used more in the present study, these tests are known for their robustness and power, and have been applied in several regions of Africa.

The complementary nature of these statistical tools justifies their choice; the Buishand test highlights breaks based on the average of the data series, while Hubert's segmentation highlights the different breaks with respect to the sequential averages 5.

The Buishand statistic is based on the following set of hypotheses: normality of the series, equality of the distribution variances on either side of the breakpoint, and the absence of self-correlation. It assumes a change of average in the series. The segmentation procedure can be considered as a stationarity test. If the procedure does not produce an acceptable segmentation of order ≥ 2, the assumption of stationarity of the series is accepted [15]. The purpose of Buishand's test is to detect a change in the average in a time series while Hubert's segmentation detects multiple breaks, if they exist in the length of series [6] [15].

The segmentation of hydrometeorological series allows us to search for multiple changes in average, by splitting the data series into several segments, so that the average of each segment is distinctly different from that of neighboring segments. Thus, from a particular segmentation of order m practiced on an initial series, we define several ranks: $k = 1, 2, \ldots, m$, in the initial series of the terminal end of the segment. One can therefore find the average of the segment, the quadratic difference between the series and the considered segmentation.

The segmentation selected at the end of the procedure implementation should be such that for a given segmentation order m, the quadratic difference is minimum and the average of two contiguous segments are significantly different. The latter has the advantage to better highlighting the trend by comparing sequences [6].

The Drought Index (DI) is used to define the level of dryness of an area. It is obtained from the ratio between annual rainfall and potential evapotranspiration. It is expressed in the following form:

$$\text{DI} = \frac{\text{P}}{\text{Etp}}$$

P: represents the annual cumulative rainfall and ETP expresses the annual potential evapotranspiration [16]. Applied in the Mo scale, the situation of the basin will be studied with regard to the drought index on the existing data series. **Table 1** shows the classification of drought conditions based on the drought index.

The hydrological variation is analyzed through the climatic balance sheet and the rainfall/flow relationship. First, the rainfall-discharge relationship is used to detect changes in surface runoff that may be related to the season, to variations in rainfall, or even to anthropogenic activities (dams, agricultural activities). The monthly discharge coefficient (MDC), the ratio between the monthly discharge and the annual discharge, is used to determine the higher water months and the

Table 1. Classification of drought conditions based on the drought index.

Drought indexes	Area classification
Is < 0.05	Hyperarid
0.05 < Is < 0.25	Arid
0.25 < Is < 0.50	Semi-arid
0.50 < Is < 0.75	Subhumid
0.75 < Is < 1	Humid

lower water months. The following relations are established with the MDC. When the monthly coefficient of flow MDC ≥ 1; the period is said to be high water, on the other hand, when the monthly discharge coefficient MDC < 1; the period corresponds to low water [9]. The monthly and interannual evolution of the water modules are analyzed and related to the rainfall to determine the periods of low flow in comparison with the rainfall, and to appreciate the rainfall-flow rates relationship.

The hydro-climatic evaluation is carried out in order to highlight the climatic deterioration on the availability of water resources in the basin. It includes the climatic balance and the hydrological balance.

The calculation of the potential climatic balance makes it possible to highlight the pluviometry deterioration on the water resources. It is determined by the following formula:

$$\text{BCP} = \text{P} - \text{ETP};$$

with P = rainfall in mm; ETP = evapotranspiration in mm; Thus:

P − ETP > 0; the year is humid or in excess.

P − ETP < 0; the year is dry or in deficit

P − ETP = 0; the year is normal.

The determination of the real climate balance sheet is the rainfall contribution to runoff and is expressed by the following formula:

$$\text{BCR} = \text{Pe} = \text{P} - \text{ETR} \text{ ; or } \quad \text{BCR} = \text{P} - \alpha * \text{ETP}$$

with Pe = effective rainfall or rainfall contribution to runoff in mm;

P = rainfall in mm; ETR = real evapotranspiration in mm, ETR = α * ETP with $\alpha \leq 1$;

α refers to the water retention in the first soil horizons. Its determination requires geological or pedological knowledge of your study area. The coefficient α reflects the water availability in the first few soil horizons. According to [7] [8] [17].

$$\text{If Pm} > \text{ETPm then } \alpha = 1 \text{ and ETPm} = \text{ETRm}$$

$$\text{If Pm} < \text{ETPm then } \alpha = \text{Pm/ETPm and Pm} = \text{ETRm}$$

with Pm: monthly rainfall rate or level and ETPm: monthly evapotranspiration.

The water balance sheet of a watershed is equal to the sum of the inflow and outflow of water in the watershed. Indeed, it corresponds to the real climate balance or effective rainfall that contributes to runoff. It is used to evaluate the availability of water resources in the watershed.

It is expressed by the formula of [18] used in hydrology which is written as:

$$BH = E(\text{input}) - S(\text{output})$$

$$E(\text{input}) = L^{®} + I + (S1 - S0);\ S(\text{output}) = Ev\ (ETP \text{ and } ETR);$$
$$P = L^{®} + Ev + I + (S1 - S0)$$

with P = rainfall or precipitation, in mm; $L^{®}$ = runoff or draining water or run-off water (mm);

Ev = evaporation or evaporated water in mm; I = infiltration or infiltrated water in mm;

(S1 + S0) = soil and subsoil stock reservoir.

In the absence of raw ETR data due to estimation difficulties

Water balance = P − ETP, with P = Pe = $L^{®}$ + ETP, so BH = $L^{®}$ − ETP

4. Results

4.1. Climate Variability in the Mo Basin

The global warming observed for more than a century does not only affect the average temperature, but also the whole of their statistical distribution, *i.e.* the whole range of possible temperatures in the place and the time (encyclopedia-environment.org). In the case of the Mo basin, the temperature extremes are studied. Data from the synoptic stations of Sokodé (1961-2018) and climatic station of Sotoboua (1982-2018) are taken into account. Over the whole watershed of the series, the average temperatures are around 26˚C, with 26.6˚C in Sokodè (1961-2018) against 26.5˚C in Sotouboua (1982-2018). The maximum temperatures are 32.7˚C in both stations compared to 20.6˚C in Sokodè and 20.3 in Sotouboua for the minimum. Thus, **Table 2** shows the difference between the average and the maximum and minimum temperatures is 6 to 7˚C which is very significant.

The extent of the Temperature increase is more apparent from the inter-annual temperature trend in relation to the available data series

Thus, **Figure 3** shows for both stations, the minimum temperatures have risen from 19˚C in the 1960s to 20.6 and 20.3˚C respectively in Sokodè and Sotouboua. As for the maximum temperatures, they have increased from 32 to 33.3 in the last decade. The coefficients of variation of the linear trend curves of minimum temperatures are 0.03 and 0.04 for the said stations, while those of maximum temperatures are 0.02 for the two stations, underlining a more pronounced upward trend in minimum temperatures.

Table 2. Key temperature data at the stations of Sokodè and Sotouboua.

	T˚C Minimum	T˚C Maximum	Average T˚C
Sokodè (1961-2018)	20.6	32.7	26.6
Sotouboua (1982-2018)	20.3	32.7	26.5

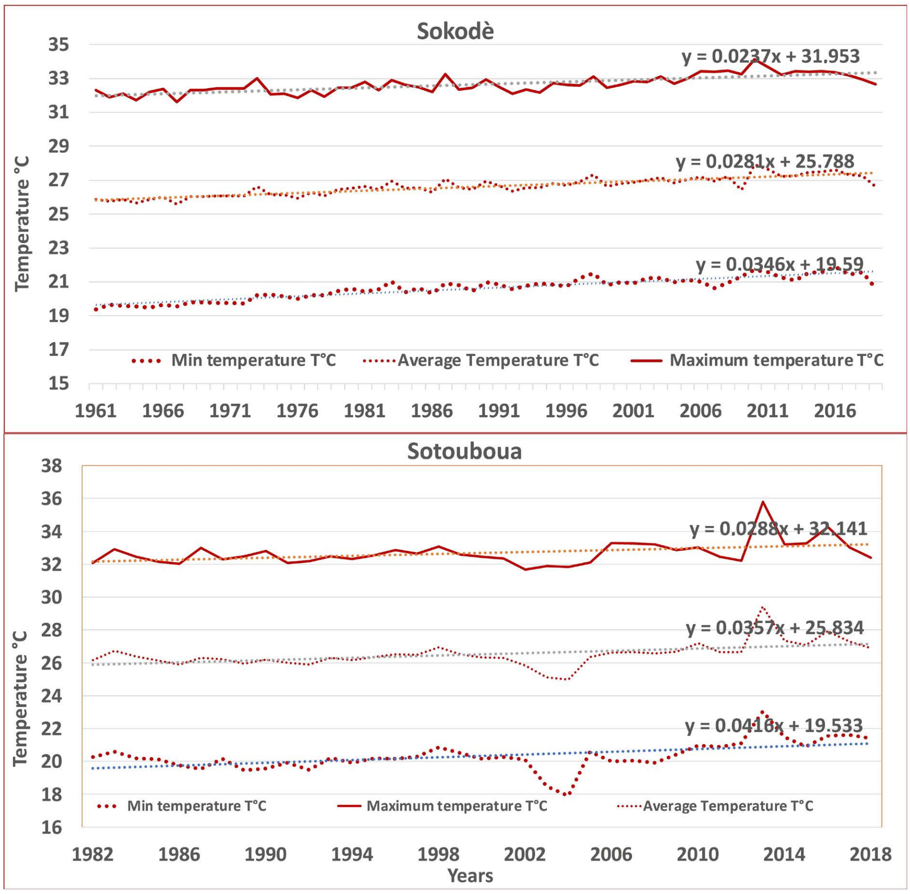

Figure 3. Interannual evolution of temperatures at Sokodè and Sotouboua stations.

The study of rainfall variability at the scale of the basin through data from the Fazao, Sokodè and Sotoutoua stations highlights the decline in rainfall from the 1960s to the present time. The results of the rainfall index supported by the moving average show that the last two decades have been the least rainy like presented in **Figure 4**.

The situation is more pronounced in Fazao, where for the last 15 years (2001 to 2015), all years have been poor; and only in 2015 has recorded its highest cumulative rainfall, but immediately followed by years with average rainfall. At Sotouboua, it is noted two humid phases interspersed with two dry phases, the second began in 2016 and is still going on. At Sokodè, after a wet phase until the seventies, a short dry period is noted between 1980 and 1990, then continues by a medium phase to dry one. **Table 3** shows that these variations are confirmed by the various statistical tests (Pettit and Hubert's Segmentation) that accurately show the break periods with respectively an increase in rainfall of 22.6% (2015) and 2.8% (1990) at the Fazao and Sotouboua stations.

At the scale of the basin, the rainfall deterioration was more pronounced at the Fazao station than at the other two sites, Sokodè and Sotouboua as represented by **Figure 5**.

While annual rainfall has decreased in recent decades, so has the number of

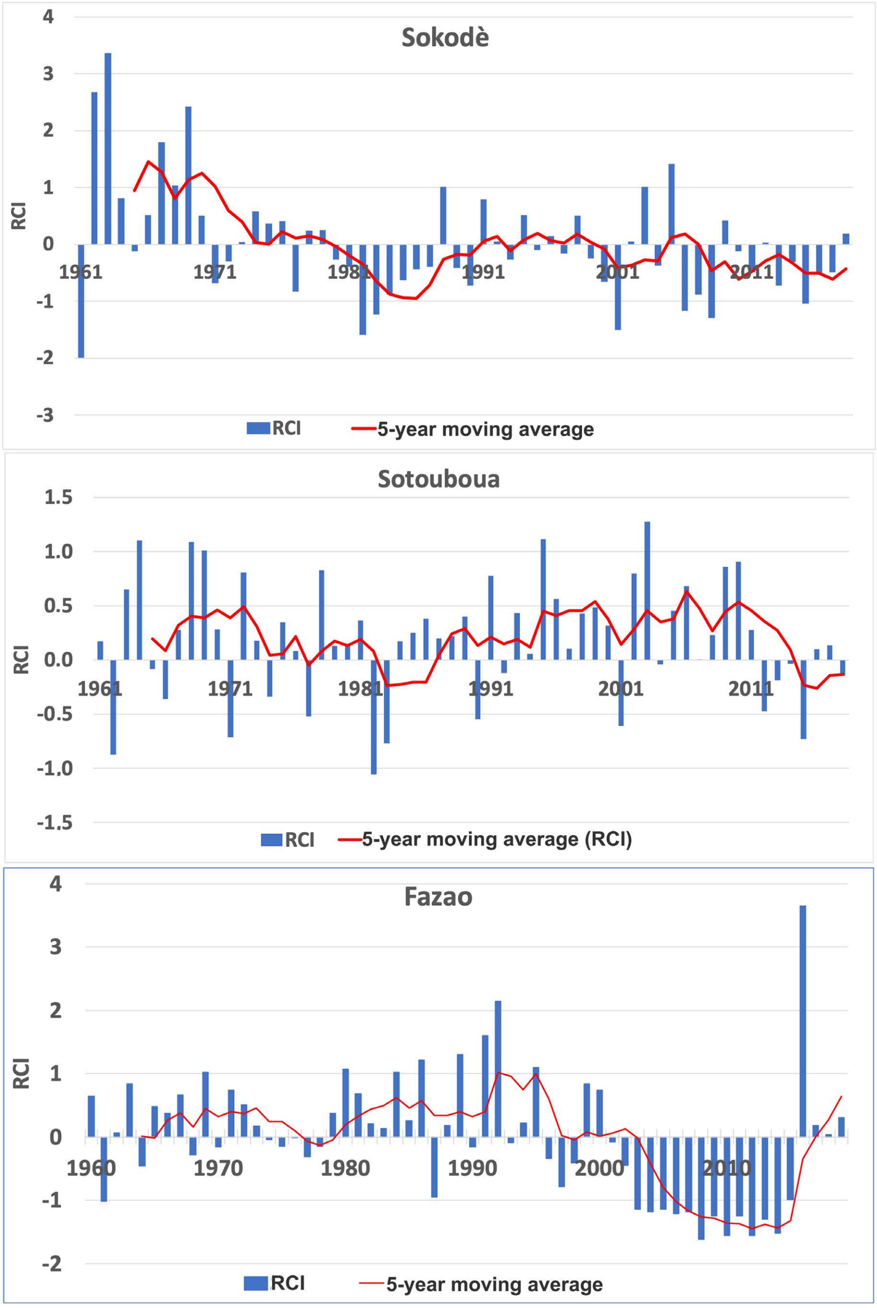

Figure 4. Rainfall indexes of Sokodè, Sotouboua and Fazao stations (1961-2018).

rainy days. In Sokodè, this number has decreased over the decades, as in Fazao, while in Sotouboua, it seems to have increased. This also shows a disturbance in the distribution of rainfall from year to year. The standards established on the whole set of data between 1961-1990 and 1991-2018 confirm the facts with 79 and 104 days of rain in Sokodè, respectively, and 98 and 85 days in Fazao as noticed in Table 4.

The correlation between rainfall and PTE is shown by the variation of precipitation height with respect to PTE. Figure 6 shows the average values of PTE that have been much higher than rainfall since the beginning of the 1980s. While

Table 3. The different breaks in the rainfall series in Fazao and Sotouboua.

Stations	Average before break (mm)	Average after break (mm)	% Increase	Year of break
Fazao	1271.0	1563.9	22.6	2015
Sotouboua	1275.9	1312.7	2.8	1990

Table 4. Number of rainy days at different stations in the Mo basin.

	Sotouboua	Sokodè	Fazao
1961-1970	97	129	97
1971-1980	63	123	91
1981-1990	78	115	104
1991-2000	114	119	88
2001-2010	101	112	85
2011-2018	96	109	81
Standard (61-90)	**79**	**122**	**98**
Standard (91-18)	**104**	**113**	**85**

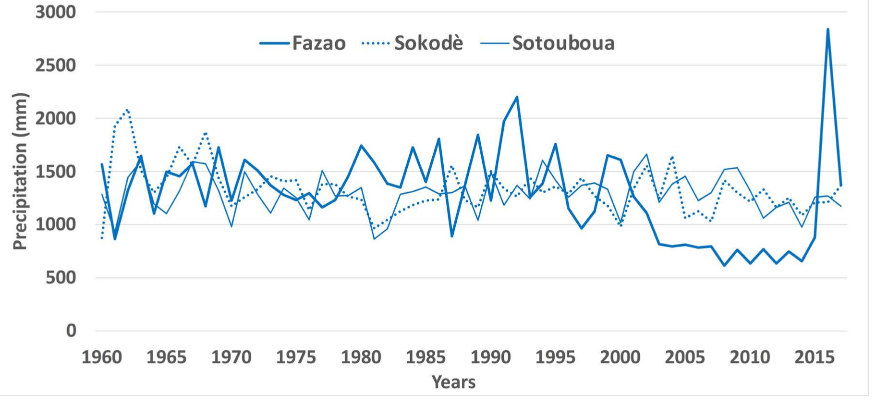

Figure 5. Interannual evolution of rainfall in the Mo basin.

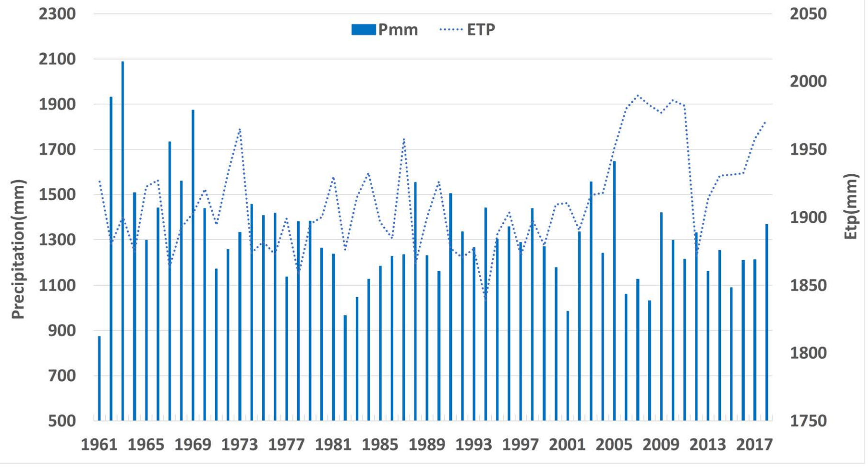

Figure 6. Comparative evolution of precipitation and evapotranspiration data.

the maximum value of rainfall is obtained in the 1960s, the maximum value of PTE is recorded in the years 2001 to 2015.

Evapotranspiration includes all the physical processes that promote the passage of water from the liquid state to the vapor state [16] [19]. It is expressed particularly in mm/day or mm/month to show the amount of water lost on a surface of 1 m^2 per day or per month. This relationship is noted by calculating the drought index which is the ratio between annual rainfall and annual evapotranspiration. Applied to the data series at Sokodè station, it emerges that, over the 57 years of observation:

- 5% are hyper-humid years, they are all located 60 to 70;
- 26% are humid, they are distributed over the entire series, this is the case for the years 1975, 1976, 1977, 1988, 1991, 1994, 1998, 2003, 2005; and
- 70% are subhumid years. They became recurrent from 1978, but permanent since 2006. The Mo watershed is in a subhumid state.

This variation in climatic conditions is not without consequence on the availability of water in the basin. This is studied with regard to hydrometric data.

4.2. Water Balance Assessment

The climatic balance sheet highlights the difference between the precipitated water sheet and the evapotranspiration. It is calculated at the watershed scale and gives information on the periods of water availability. It is a matter of establishing the potential climate balance sheet, from the potential evapotranspiration and the actual climate balance, from the actual evapotranspiration. The climatic balance sheet, whether it is potential or real, establishes the climatic pejoration on the water resources or analyzes the Hydrological surface in a basin.

The monthly potential water balance sheet at the Sokodé station identifies four wet months (June, July, August and September) out of the six rainy months (May, June, July, August, September and October) of the year as noticed in **Figure 7**. They are the months in which rainfall exceeds potential evapotranspiration (PTE) and where runoff is noted. These months correspond to the period when soil reserves are filled and contribute to groundwater recharge.

At the annual level, the real climatic balance sheet makes it possible to highlight the wettest years in the series. **Figure 8** shows that the years 1962 and 1963 had an annual rainfall greater than the annual evapotranspiration. The other years are consequently dry and this climatic drought strongly influences the hydrology of the rivers. Its impact is the decrease in the water sheet flowed or drained.

4.3. Hydrological Variability in the Mo Basin

The hydrological regime of a river is defined by the variations in its monthly and interannual flow rate noted in m^3/s. The analysis of hydrographs at the ten-year time step shows highly variable and decreasing flows at the Kama-Bassar and Boulougou stations, where the flows are the highest as shown in **Figure 9**.

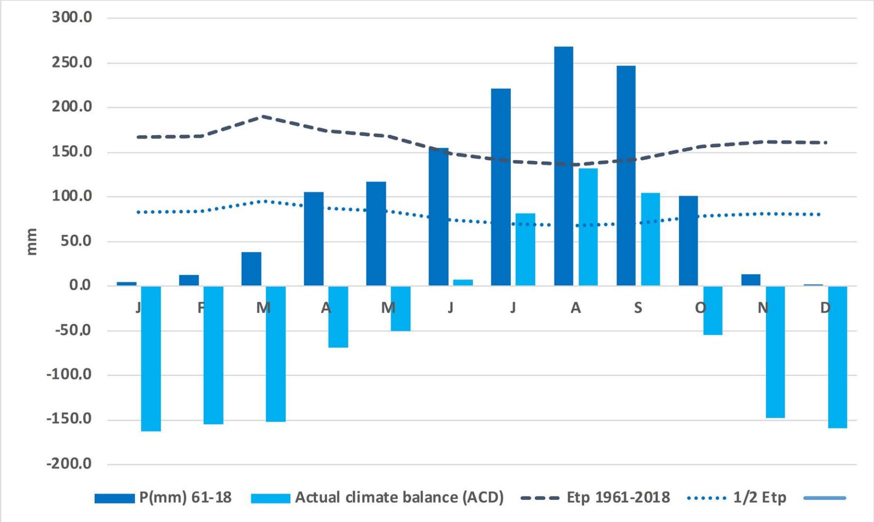

Figure 7. Monthly potential climatic balance sheet at Sokodé station.

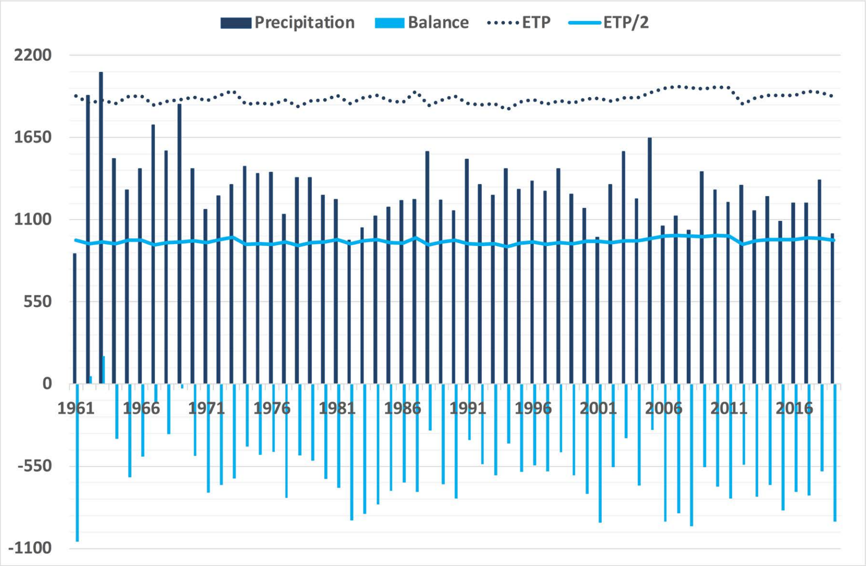

Figure 8. Annual water balance sheet at the Sokodé station.

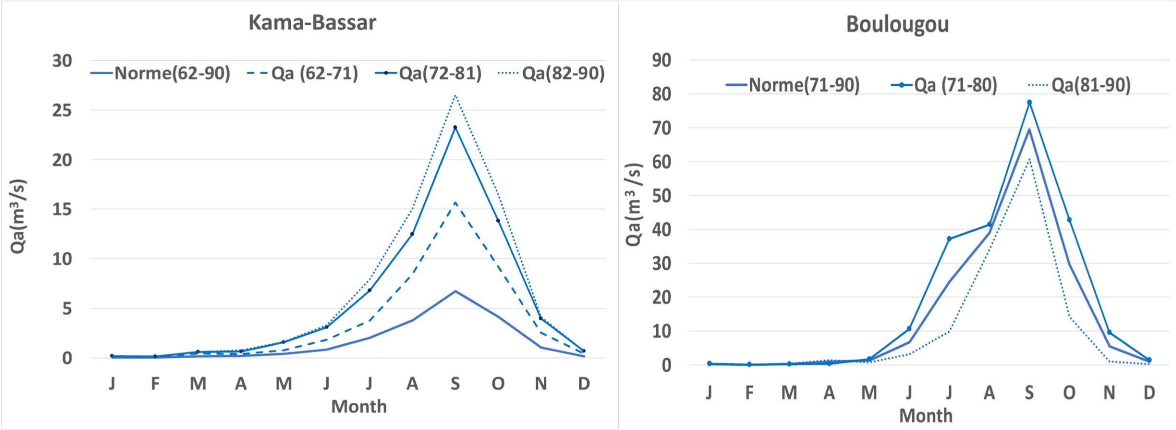

Figure 9. Comparative evolution of decennial flows at Kama-Bassar and Boulougou.

The hydrological season extends from July to October and the peak flows are obtained in September. On Kama-Bassar, the September peak has evolved upwards (4.63 m^3/s in 1962-1971; 4.06 m^3/s in 1972-1981; and 2.63 m^3/s in 1982-1990) over the 28 years of observation. On the other hand, on Boulougou, the peak flows are downwards (77.45 m^3/s in 19721-1980 and 60.75 m^3/s in 1982-1990) over the 20 years of data collection The average values are respectively 3.79 m^3/s on Kama-Bassar and 69.43 m^3/s on Boulougou. The analysis of hydrographs shows the influence of rainfall on the monthly flow regime.

Figure 10 shows that there is one-month lag between the peak of rainfall in August and the peak of runoff in September.

Despite the uneven length of the observation data, **Figure 10** shows that surface runoff occurs only during the months of June through November. The other months of the year are periods when the rivers dry up, particularly from December to May. Seasonally, the variation allows to observe a low water regime in the dry season (February-April) and a flood regime in the wet season (August-September). The rains in May contribute to the saturation of the soil, hence the first runoff in June. The hydrological peaks are often disrupted by socio-economic activities. The recession which began in October reaches its critical level between December and January and the low water level occurs very early in February and is maintained until the end of April with a zero runoff.

The value of the average flow estimated at 20 m^3/s by [13] at the end of the 1960s is less than 15 m^3/s at the end of the 1980s and 1990s. During the same period, the value of the maximum flow estimated at 80 m^3/s, is fallen to 75 m^3/s, a reduction of more than 5 m^3/s. The variation in flows is closely correlated with the pluviometry variation.

Figure 11 shows that the annual runoff is generally low, less than 40 m^3/s on the main river, Boulougou. The years 1978, 1979, 1989 are marked by annual module flows above 20 m^3/s. The other years have much lower flows and the situation is more pronounced at the Kama-Bassar station with flows below 1.6 m^3/s. The years in which the annual flow on the Boulougou is greater than 20 m^3/s are high water years; on the other hand, years in which the average flow is lower than this reference value are low water years. When the average maximum flow is higher than 80 m^3/s, it is an exceptional flood year. The years 1978, 1979, 1985, 1988 and 1989 are in the case with a maximum flow rate varying between 17 and 35 m^3/s. The other years are below the threshold of 20 m^3/s with values going to 4.5 m^3/s.

The calculation of flow rate coefficients allows confirmation of the periods of surface flow and water availability. Based on data from the Boulougou station, which has the highest flow rates, flow coefficients are calculated to highlight the contribution of the different months in **Table 5**.

Thus, July, August, September and October have the highest coefficients, contributing to an average of 10% or more of the runoff. On the whole, the four rainy months provide more than 80% of the runoff of the hydrological year. The maximum flows are all recorded during these rainy months, with August in par

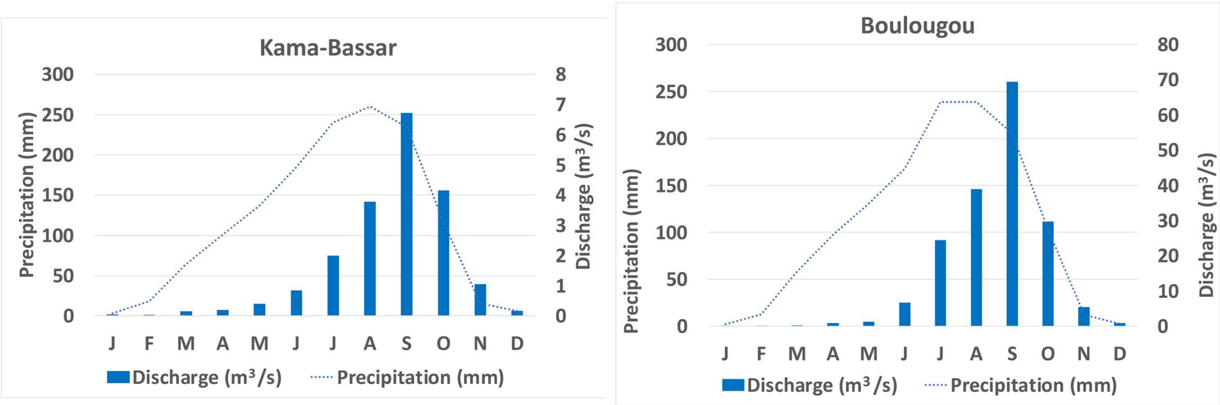

Figure 10. Evolution of inter-monthly rainfall/flows, Kama-Bassar (62-90) and Boulougou (71-90).

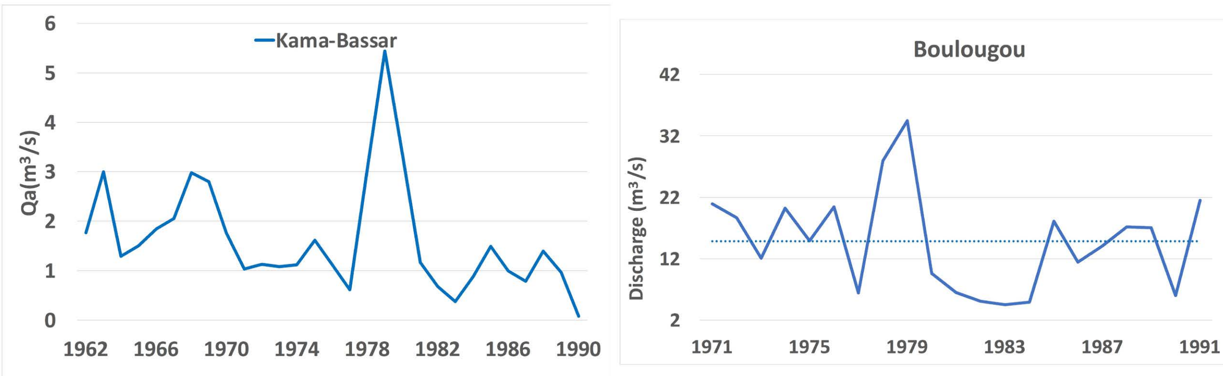

Figure 11. Inter-monthly rainfall/flow evolution, Kama-Bassar (62-90) and Boulougou (71-90) rivers.

Table 5. Seasonal variability of statistical parameters of the flow on the Boulougou river.

1971-1980	J	F	M	A	M	J	J	A	S	O	N	D
Qa (m^3/s)	0.39	0.09	0.16	0.35	1.61	10.61	**37.19**	**41.41**	**77.45**	**42.71**	9.59	1.34
MDC	0.02	0.01	0.01	0.02	0.09	0.61	**2.13**	**2.37**	**4.43**	**2.44**	0.55	0.08
Absolu Max	1.57	0.41	1.45	0.99	5.11	32.01	**84.21**	**88.47**	**156.26**	**98.31**	42.22	3.64
Absolu Min	0.00	0.00	0.00	0.02	0.10	1.48	3.50	4.29	34.40	20.84	0.60	0.00
1981-1990												
Qa (m^3/s)	0.06	0.01	0.36	1.36	0.72	3.17	9.77	34.08	60.75	14.23	0.96	0.23
MDC	0.01	0.00	0.03	0.13	0.07	0.30	0.93	**3.25**	**5.79**	**1.36**	0.09	0.02
Absolu Max	0.32	0.12	2.29	10.50	2.31	8.59	20.92	**67.09**	**136.89**	**30.97**	2.45	1.02
Absolu Min	0.00	0.00	0.00	0.04	0.04	0.48	4.72	5.19	7.90	1.73	0.13	0.00

Qa (m^3/s): Flow; MDC: Average flow coefficient; Max and Min absolute: Maximum and minimum absolute flow.

ticular having the highest flow of 156.26 and 136.89 respectively in 1971-1980 and 1981-1990.

5. Discussion

The analysis of climatic and hydrometric data has made it possible to characterize the hydro-climatic variability in the Mo Basin over the last 50 years. The methods which are used have been likewise used in different research works in West Africa to evaluate the climate impacts on the natural and human resources. It is noted an increase in temperature and evapotranspiration, but a significant decrease in precipitation and runoff since the 1970s. The increase of the temperature has been more remarkable as well in terms of minimum temperatures as in terms of maximum temperatures. It is 1.6˚C for minimum temperatures and 1.3˚C for maximum temperatures. This variability of hydro-climatic parameters has been highlighted by several authors [10] [14] [20]. These results are consistent with those of [21] on the study of climate change in Togo, [9] on the study of rainfall variability in the Volta-Mono area and [8] in the Mono-Ahémé-Couffo basin in Togo and Benin. The results of these authors highlight regional variability. However, in the Mo Basin, some particularities are noted between Fazao, Sokodé and Sotouboua, although they are located in the same climatic zone.

These variabilities are linked to the presence of mountains and forests, which induce relative stability in Sotouboua, whereas in Fazao the impact of the pejoration is more sensitive. The impact of rainfall was directly observed on surface water resources through flow deficits in the Mo basin, as it is the case in other basins in the sub-region [8] [22]. The rainfall breaks recorded at the Fazao and Sotouboua stations mark important changes in the supply of water resources. They contribute to a slight increase in surface flow rate. However, this increase is not sufficient for the supply of groundwater.

This low flow rate is a sign of the degree of drying of the soils and the weak influence of the precipitations of the first months of rain. The soils having remained dry for a long time (December to May), the first rains (April-July) are used to humidify them. Alterities act as a sponge and retain water for a relatively long time. The sponge effect of the alterities also explains the difference between the rainy peak and the hydrological peak. After the rainy peak of August, the sponge effect of the alterities continues and is felt on the flows which decrease [9].

Generally, the recharge of the water tables raises the water level in the beat zone, which becomes closer to the ground surface and thus facilitates surface runoff. As soon as the rains stop, the water table level drops and surface runoff is also affected, hence the low flows in August. The memory effect of the watershed should be emphasized to explain the shifts due to the presence of the various tributaries of the main rivers, ponds and other depressions in the watershed that delay or attenuate the movement of water between rainfall peaks and hydrological peaks.

Low flows, fairly close to zero (low water flows) are recorded from December to June, maintaining low flows, not zero. The month of February has the lowest minimum (zero) and maximum (0.41 and 0.12 m^3/s) flows on the Boulougou, depending on the decade. However, this low flow rate means that the contribution of rainfall to the runoff is not very important, or steady weak, and that only the underground aquifers support the low water flows.

The analysis of the different climatic and hydrological parameters showed the hydro-climatic instability that has prevailed in the Mo watershed between 1961 and 2019. Water resources are the most affected by this instability. The availability of surface water has decreased significantly during this period as likewise noted by [22] [23] [24], in the Oti Basin. Since runoff is directly dependent on rainfall. The supply of groundwater has progressively decreased, since it is dependent on the infiltration of rainwater that percolates into the lower layers of the soil. The water reserves of the soil or subsoil (subsurface reserves) have also been reduced, leading to a slowdown in the vegetation cover.

The diversity of geological substrates has played its part in the fall of infiltration flows and flow, with the consequence of low infiltration. The fluctuations of the runoff in the lower valley of the Mo, determines the role played by the geological substratum in the flow process and also the geomorphological dynamics of the river, due to the evolution of sedimentary deposits and the development of agriculture [12].

6. Conclusions

This study analyzed the influence of hydro-climatic data in the Mo basin. The results are the climatic variability in the Mo River Basin, as indicated by the increase in minimum and maximum temperature data, the decrease in rainfall from the 1970s to the present day and the reduction in the number of rainy days during the same period. The climate balance highlights the difference between the precipitation water balance and evapotranspiration. The monthly potential water balance of the Sokodé station identifies four wet months (June, July, August and September) out of the six rainy months (May, June, July, August, September and October) of the year. Observation data show that surface runoff only occurs during the months of June to November. Rainfall varies from 636 to 2200 mm on the mountains (Fazao and Alédjo) and 1000 to 1500 mm in the lowland area, plateau and hill areas. The rain, the primary factor determining the runoff and availability of water resources in the watershed, impacts all other bioclimatic factors. The decrease in rainfall and the increase in temperature, evapotranspiration, drought, and remarkable changes in the climate in general, could cause difficulties in obtaining water. This unmet basic need would lead to water stress and even food insecurity. Our findings are closer to those of other West African authors, a certain concordance of climatic facts in time and space in the sub-region is noticed. However, the hydrological dynamics prevailing in the basin induce remarkable impacts on the vegetation and on the surface dynamics of the basin that would be very interesting to study.

This research suffered from insufficient observation data, in particular the unequal duration of observation of the hydrological data of the two reference stations and the long duration of rainfall observation of one station in relation to the other. This situation did not always allow comparative analyses to be made.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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