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Article

Long-Term Evolution of Rainfall and Its Consequences on Water Resources: Application to the Watershed of the Kara River (Northern Togo)

Mozimwè Ani [1,2], Jessy Jaunat [1,*], Béatrice Marin [1], Marie Barel [1] and Kissao Gnandi [2]

1 GEGENAA-EA 3795, University of Reims Champagne-Ardenne, 2 Esplanade Roland Garros, 51100 Reims, France; paulinani11192@gmail.com (M.A.); beatrice.marin@univ-reims.fr (B.M.); m.armandine.barel@gmail.com (M.B.)
2 Département de Géologie, University of Lomé, Bvd Gnassingbé Eyadema, Lomé 01 BP 1515, Togo; kgnandi@yahoo.fr
* Correspondence: jessy.jaunat@univ-reims.fr

Abstract: The Kara River watershed (KRW), northern Togo, is facing climate-change impacts that have never been clearly characterized. Six decades of rainfall data (1961–2020) from six measuring stations ideally distributed across the watershed were used in this study. The flow records from two stations situated in contrasting locations on the KRW were also used. Statistical tests were conducted to assess the spatial and temporal variability of the rainfall and to detect tendencies within these meteorological series. The water balance method and calculation of the dry-off coefficient and of the groundwater volume drained by rivers allowed evaluating the impact of climatic evolution on surface flow and on groundwater volumes during the six decades studied. The results showed contrasting spatiotemporal variability of rainfall (and of aquifer recharge) over the watershed with a decreasing tendency upstream and an increasing one downstream. At the same time, the water volume drained by the aquifer to sustain the river's base flow decreased from −22% to −36% depending on the measuring station. These results constitute a decision-making tool for Togolese water resource managers and are of primary importance for characterizing the fate of water resources worldwide in regions subject to severe droughts.

Keywords: climate change; climatic break; aquifer recharge; drought; western Africa

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1. Introduction

Groundwater is an important water supply source and contributes to surface freshwater base flows [1]. Therefore, it is worth understanding the impact of climate change on these water resources. Climate change can impact a watershed's hydrological processes and lead to water supply difficulties for the populations that rely on the resource [2]. In combination with certain factors such as insufficient access to drinking water and sanitation, droughts enhance the vulnerability of many African populations [3]. According to Döll et al. [4], the most vulnerable areas are mainly located in Africa and in South America.

Indeed, between the end of the 1960s and the beginning of the 1970s, the Sahelian regions of western Africa suffered a drought that marked a change in the climate regime [5]. This drought had long-term effects, particularly on regions located in the Gulf of Guinea [6–8]. Thus, rainfall and hydrometric deficits were confirmed with a modification of the rainfall–flow relationship in this geographic zone [9,10]. All of these authors used tests from the ICCARE program (Identification and Consequences of Climate Variability in Non-Sahelian Western Africa) to understand the changes that have come about in these climatic regimes. These tests include the Pettitt test [11], Lee and Heghinian test [12] and

Hubert's segmentation [13]. The analysis of rainfall tendencies is an essential element for characterizing the consequences of climate change on water resources. The concept of tendency within a hydrometeorological series corresponds to the evolution of its parameters throughout time, independent of seasonal fluctuations [14]. Break tests coupled with tendency tests have often been reported in the literature for the characterization of tendencies within chronological series of climatic data [15–19]. Analyzing past tendencies became an efficient tool for planning, conception and management of water resources, providing valuable information for predictive approaches to evaluate future changes in hydroclimatic parameters [20,21].

During the last years, numerous research studies have used parametric and non-parametric tests to define tendencies within chronological series [22–31] The most commonly used are the Mann–Kendall [32,33] and Sen [34] tests. More recently, Sen [35] developed a new methodological approach, the innovative trend analysis (ITA), to detect tendencies in chronological data series. In contrast to the other methods mentioned above, the advantages of this method are: (1) the dataset does not require any hypothesis to be verified and (2) it is based only on the comparison of the two halves of the original temporal series [36]. This method has been used, for example, in Turkey [37], Nepal [38] and Ethiopia [28]. For instance, Girma et al. [39] applied the ITA method to the upper basin of the Huai River in China to show that the basin's precipitation is characterized by a high variation coefficient during the summer season, and that the annual rainfall had a statistically significant increasing tendency at the Fuyang station during the period 1960–2016. Additionally, by applying this same method to 16 measuring stations in northeast Algeria, Besma et al. [40] predicted that, in the future, some stations will measure drought periods while others will be confronted with significant flooding risks.

The evolution of climate variability and its impact on water resources have been approached by several authors from western Africa [41–44]. Because of limited storage volume and short residence time, bedrock aquifers are particularly dependent on annual rainfall that ensures their recharge. According to Döll et al. [4], the recharge volume could fall by 10% in the most vulnerable zones by 2050. In Togo, Badjana et al. [45] have shown evidence of decreasing precipitation in the extreme northern part of the country during the period 1960 to 2010. More recently, studies conducted in northern Togo [46] have pointed out variability in precipitation and temperature series with significant impacts on cereal production. On the contrary, the examination of precipitation and temperature at the watershed of the Mono River, which is located both in Benin and Togo, revealed a tendency of increasing rainfall and temperature by 2050 [17]. This illustrates the spatial variability of rainfall indices [19]. Thus, the watershed's scale seems the one most adapted to comprehend the hydroclimatic function and tendency within chronological rainfall series. It is in this framework that this study was initiated, to assess the rainfall tendency in the Kara River watershed (KRW) and to highlight its impact on water resources. This research study aims at (i) analyzing statistically the chronological rainfall series and flow data series of the Kara River, (ii) determining rainfall tendencies and analyzing their spatial variability, (iii) analyzing temporal variability of aquifer recharge and, finally, (iv) analyzing the temporal variation of the water volume mobilized by the basin's aquifers to sustain base flow.

2. Study Area

The KRW is a subwatershed of the Oti watershed representing 9.5% of its surface. It is located in the Kara region, one of the five regions of Togo (Figure 1). It extends within the 9°25′ and 10°10′ parallels of northern latitude and the 0°15′ and 1°30′ meridians of eastern longitude. It partially covers the prefectures of Kozah, Binah, Assoli, Guérin-Kouka, Bassar, Doufelgou, Kéran and a very small part of the Oti prefecture (savannah region). It expands to Benin where the Kara River has its source. In this study, only the

Togolese part, which has a surface area of approximately 5000 km², was taken into account. It is essentially drained by the Kara River and its tributaries and has a dendritic network.

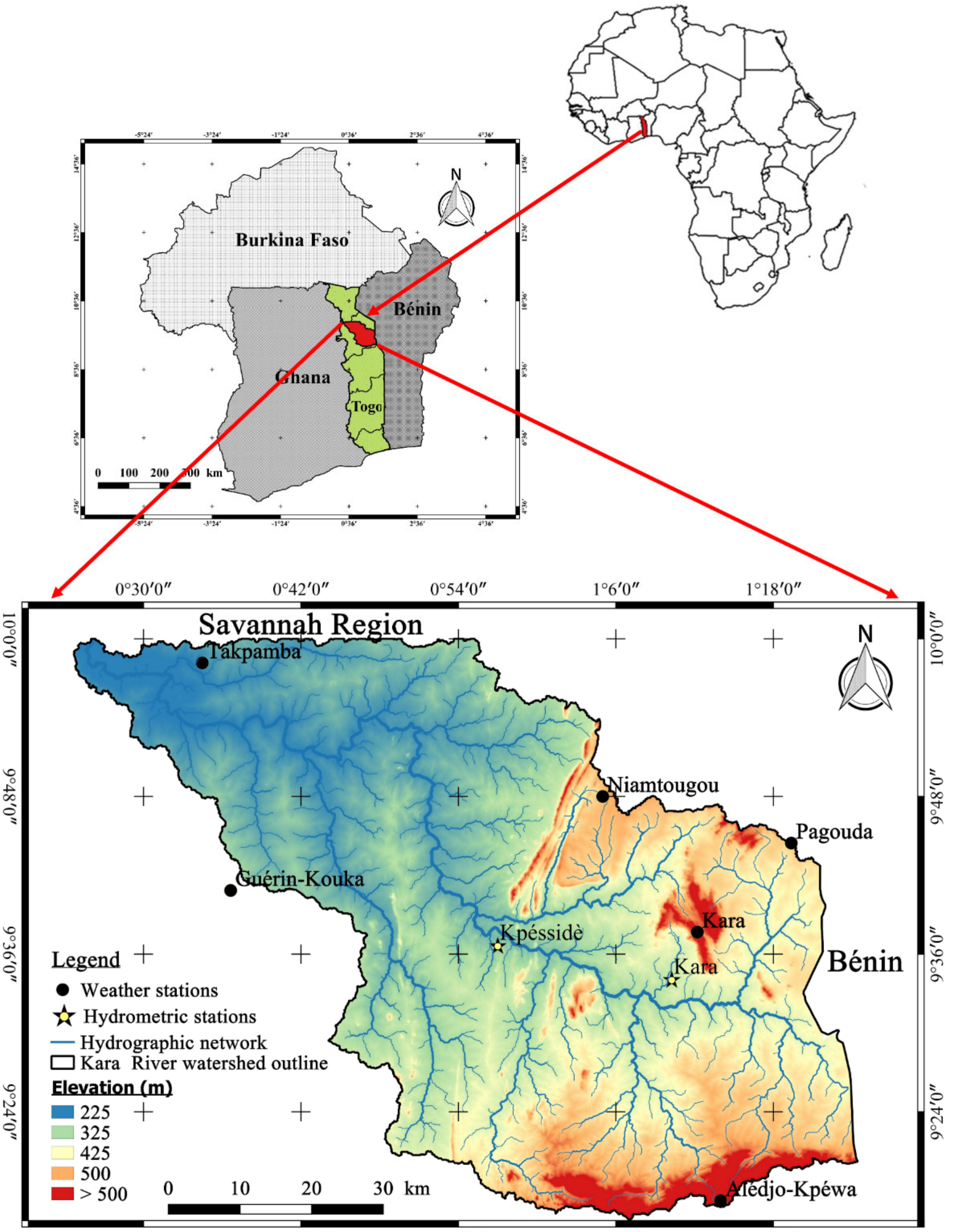

Figure 1. Geographical location, relief of the study zone and location of the different measuring stations.

The climate of the Kara River watershed is characterized by two distinct seasons: a dry season lasting from November until March and a wet season lasting from April until October. The average annual rainfall recorded for the last six decades is 1310 mm ± 96.9 mm. The rainiest months are July, August and September (Figure 2).

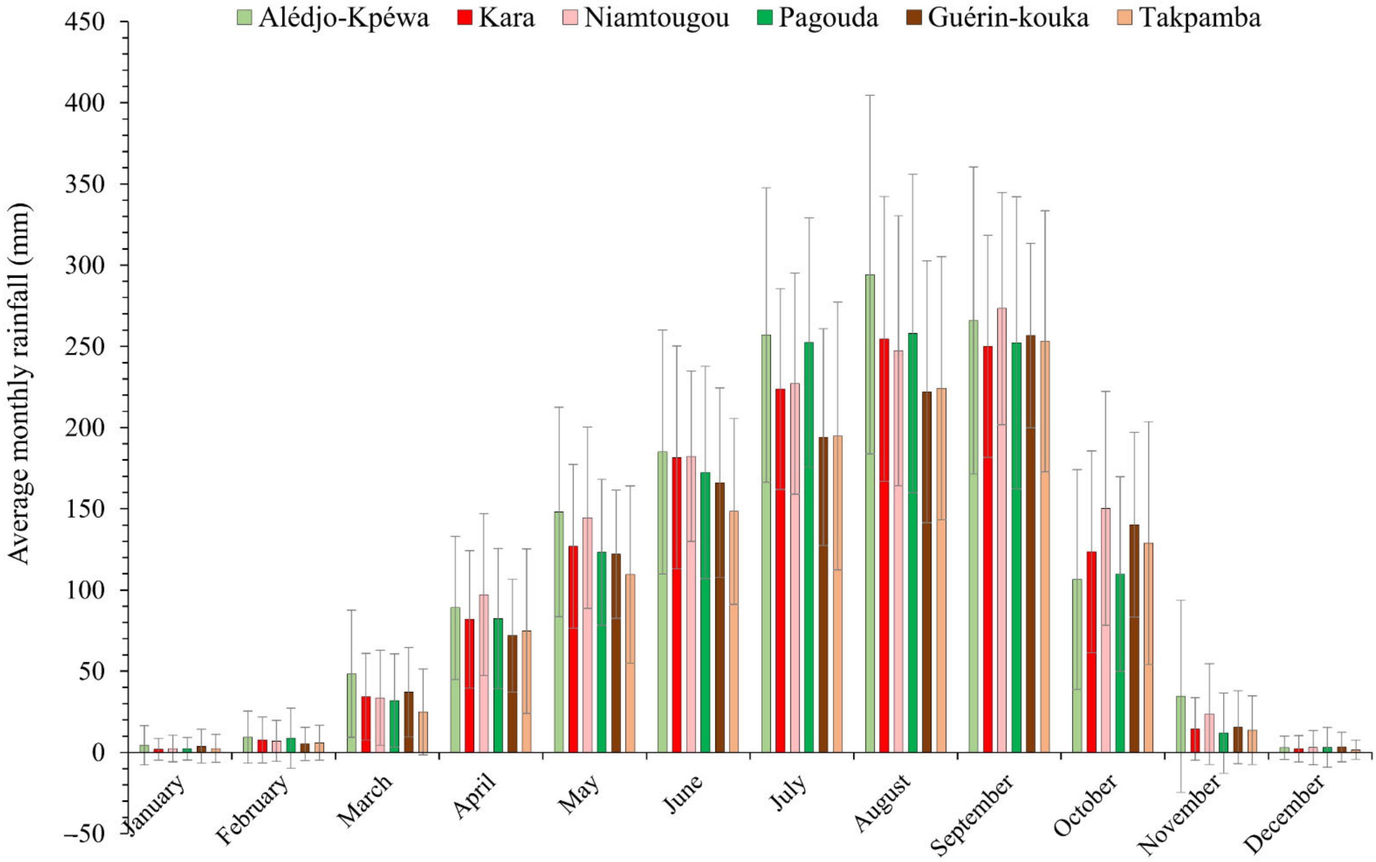

Figure 2. Average level of monthly rainfall at the studied stations between 1961 and 2020 (the location of the stations is presented in Figure 1).

From a geological point of view (Figure 3), the following structural entities occur from east to west [47,48]: (i) the granulites of the suture zone; (ii) the structural unit of Kara–Niamtougou, essentially composed of orthogneiss; (iii) the structural unit of Atacora, essentially composed of quartzites and sericite schists; (vi) the structural unit of Buem, composed of sandstone quartzites in the form of veins; (v) greenish sandstones associated with shales belonging to the great group of Pendjari of the Volta watershed, crossed by hematitic and alluvial formations.

On the hydrogeological level, two main aquifer reservoirs can be identified from surface to depth: an alterite reservoir and a fractured/fissured reservoir. The whole fractured/alterite level acts similar to a unique aquifer system of bilayer type [49]. The wells tapping the water of the alterite reservoir within the first fifty meters of depth are traditional sinks that become dry during the low-water period. The water of the reservoir with a fractured base is exploited by boreholes extending from 40 to 100 m in depth; these sinks provide water year-round (Figure 4).

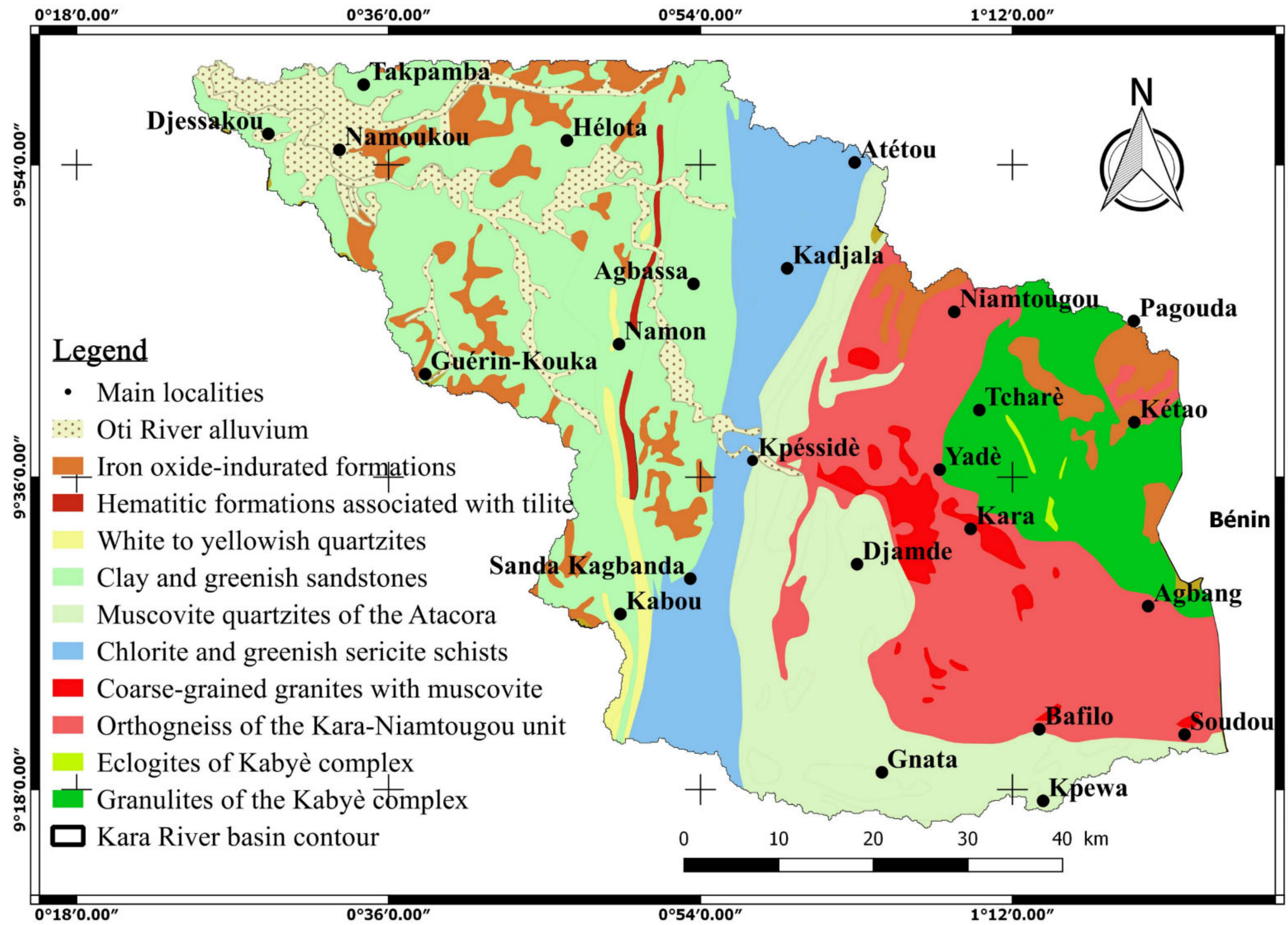

Figure 3. Simplified geological map of the Kara River watershed (modified after General Directorate of Mines and Geology, 1986).

Figure 4. Traditional sinks exploiting the water of the alterite reservoir at Niamtougou (northwest of the study zone) (**a**) and borehole equipped with a human-operated pump, exploiting the water of the fractured reservoir at Bébéda (center of the study zone) (**b**).

3. Material and Methods

3.1. Data Used

Hydroclimatic (precipitation and temperature) and hydrometric (flow) data were used for this study (Table 1 and Figure 1). The hydroclimatic data were provided by the National Directorate of Meteorology of Togo. Hydrometric data were provided by the Directorate of Water Resources of Togo and concerns only the Kpéssidè and Kara stations (which are located southeast of the city of Kara, on a tributary of the Kara River; Figure 1). Unfortunately, this hydrometric measurement network is no longer active since the early 1990s.

The precipitation records of the meteorological station of Guérin-Kouka showed significant gaps for certain months and/or even years. Unfortunately, this station is the only one located in the southwest part of the studied watershed. The missing data were completed to facilitate the analysis and ease the interpretation of the results. According to [50], missing or erroneous data of a station can be estimated based on the values of nearby stations if they are subject to the same weather conditions and located in the same geographic zone. To highlight the geographical heterogeneities of precipitation, the monthly and annual precipitation data of this station were thereby completed by those of Takpamba. These two stations are approximately 30 km apart, following a north–south axis, and are located in a similar hydroclimatic context.

3.2. Spatiotemporal Variability of Rainfall

3.2.1. Standardized Precipitation Index (SPI)

The standardized precipitation index (SPI) or Nicholson index [51] enables the detection of precipitation variations within a long series of observations. It allows for the calculation of the drought level or the exceeding amount of rainfall in a given region [14,52]. It is defined by Equation (1):

$$SPI = \frac{(Xi - Xm)}{\sigma} \quad (1)$$

where *Xi* is the precipitation for the year, *Xm* is the average precipitation of the study period and σ is the standard deviation of the annual rainfall that occurred during the study period. Negative values indicate a rainfall deficit during the period and positive values define excessive rainfall amounts.

3.2.2. Hanning's Low-Pass Filter

Hanning's low-pass filter of order 2, also called the weighted–reduced–centered moving average, enables the elimination of seasonal variations in a chronological series. This method, applied to long precipitation series, is explained elsewhere [8,53,54].

Reduced–centered indices of rainfall amount obtained with this method are useful for distinguishing periods with a deficit of rainfall from periods with an excess of rainfall. Thus, it is possible to identify normal, wet and dry periods within a chronological series. A period is said to be normal when a fluctuation between positive and negative values of the computed index is observed. A period is indicated to be wet when the annual rainfall is superior to the average rainfall (positive index). A period is dry when the annual rainfall is inferior to the average rainfall (negative index).

Table 1. Characteristics of the hydrometric and hydrological stations. (Meteo. = meteorological; Hydro. = hydrometric; Long. = longitude; Lat. = latitude; Obs. = observation; Var. Coef. = variation coefficient).

Station Type	Localities	Geographical Coordinates		Measured Data	Obs. Period	Time Step Used	Average Rainfall/Flow (mm)/(m³/h)	Var. Coef. (%)
		Long. E	Lat. N					
Meteo.	Kara	1.203	9.628	Temperature + Precipitation	1961–2020	Monthly	1303 ± 202	16
	Niamtougou	1.083	9.773	Temperature + Precipitation	1961–2020	Monthly	1386 ± 211	15
	Pagouda	1.323	9.741	Temperature + Precipitation	1961–2020	Monthly	1308 ± 243	19
	Alédjo-Kpéwa	1.233	9.287	Temperature + Precipitation	1961–2020	Monthly	1445 ± 255	18
	Guérin-Kouka	0.611	9.608	Temperature + Precipitation	1961–2020	Monthly	1238 ± 184	15
	Takpamba	0.5746	9.969	Temperature + Precipitation	1961–2020	Monthly	1177 ± 234	20
Hydro.	Kpéssidè	0.9555	9.617	Flow	1962–1992	Daily	29 ±10.9	38
	Kara	1.2833	9.533	Flow	1954–1990	Daily	20 ± 9.4	47

3.2.3. Geographical Precipitation Analysis

To assess the geographical repartition of rainfall over the watershed, an interpolation based on the kriging method was performed using Surfer software (Version 16). Hence, decennial rainfall was mapped to characterize the evolution and the repartition of rainfall during the six decades studied (1961–1970, 1971–1980, 1981–1990, 1991–2000, 2001–2010 and 2011–2020).

3.2.4. Break in Precipitation

According to Lubès-Niel et al. [55], a break is defined by a change in the probability law of the random variables, of which successive realizations define the studied chronological series. To highlight climatic breaks, several methods were previously used: the Pettitt test [11], the Bayesian method of Lee and Heghinian [12], and Hubert's segmentation method [13]. The use of these statistical methods is justified by their robustness. Based on the literature [6,7,55], we choose to use these three methods to detect statistical breaks in the precipitation levels during the period considered. These three statistical methods were applied to our data by utilizing Khronostat software (Version 1.01). which was developed by the mixed research unit for Hydrosciences of Montpellier [56].

3.2.5. Long-Term Trends of Rainfall

The Mann–Kendall non-parametric test [32,33] explores the tendencies within a data series without specifying whether the tendency is linear or not [57]. The Mann–Kendall tendency test is a simple and robust test that accepts missing data but hardly detects annual trends [14]. This test was used in other studies to evaluate the importance of a trend within chronological series of climatic data [20,22,24–27,58–60]. A positive value for the Mann–Kendall slope expresses an upward trend and a negative value implies a downward trend.

The Sen test [34] is used when the trend is thought to be linear [57,61]. A positive value for the Sen slope expresses an upward trend and a negative value implies a downward trend [57].

Finally, the method of innovative trend analysis (ITA) was recently developed by Şen [35,36]. It enables a visual inspection and an identification of categorical tendencies within chronological data [37]. The most commonly used methodology is the Mann–Kendall (MK) method, but it requires some basic assumptions, which may not be valid in natural hydroclimatological series. The ITA method used in this paper does not require any assumptions and is based on the comparison of the two ascending ordered halves from the original time series. The steps of this method follow:

- The temporal data series is subdivided into two parts (the first and the second half of the record) and the rainfall levels are ranged in increasing or decreasing order.
- The arranged rainfall data are then placed in a dispersion diagram (rainfall levels of one half of the series versus rainfall levels of the other half of the series) with equal vertical and horizontal scales. The curves thus obtained are then compared with the line curve: y = x.

There is no significant trend if the dispersion of the points occurs along the straight line of slope value equal to 1. If the dispersion of the points is below or above the unitary line curve, then a significant tendency either upward or downward exists. Based on random variables, five types of trends can be discriminated: a trendless times series, a monotonic positive trend, a monotonic negative trend, a non-monotonic positive trend and a non-monotonic negative trend [37].

3.2.6. Water Balance

To estimate the aquifer's recharge rates, the water balance method was adopted. Numerous methods describe ways to evaluate the parameters for the water balance (e.g., the Penman method [62], the Thornthwaite method [63] and the Turc method [64]). Considering the available data, the Thorntwaite method was selected because it only requires rainfall, temperature and the station's latitude data. As reported in the literature, this method is regularly used to estimate water balance parameters (e.g., [65–67]). The parameters computed via this method are the potential evapotranspiration (PET), the actual evapotranspiration (ETa) and the effective precipitation (EP). In this study, we used a value for the useful water reserves (UWR) of 100 mm, in agreement with work to estimate the recharge of the base aquifers in the plateau regions of Togo [68], carried out in a similar environment.

Runoff was estimated based on the empirical formula from Tixéront and Berkaloff, as reported in [69]. This method uses the evapotranspiration value computed with the Thornthwaite method by using the following equation:

$$R = \frac{P^3}{3 \times PET^2} \tag{2}$$

with R: runoff (mm), P: precipitation (mm) and PET: potential evapotranspiration (mm).

3.2.7. Recession Coefficient and Water Volume Mobilized by the Aquifers

The analysis of the rivers' drying constitutes a fundamental aspect for comprehending the watershed's function during the low-water period. In absence of precipitation, the flow of certain rivers is reduced to only groundwater contributions from the aquifer [70]. The analysis of recession episodes thus enables determination of the contributions coming from the aquifers and the drainage rhythm of the underground reservoirs.

Different mathematical methods are suggested for calculating the recession coefficient and the water volume mobilized by the aquifers: [71–73]. All of these methods are inspired by the Maillet model; in this study, we used dichotomous resolution, which is widely mentioned in literature (e.g., [73–76]).

In this method, the expression of the dry-off coefficient is given by Equation (3):

$$\frac{e^{-kt}}{k} + \frac{V}{Q_0} + \frac{1}{k} = 0 \tag{3}$$

with Q_0: initial flow ($m^3 \cdot s^{-1}$), k: recession coefficient (day^{-1}) and t: time (s).

The water volume mobilized by all of the watershed's aquifers is then given by the expression:

$$V_{mobilised} = \int_0^{+\infty} Q_0 \cdot e^{-kt}\, dt = \frac{Q_0 \times 86{,}400}{k} \quad (4)$$

4. Results and Discussion

4.1. Spatiotemporal Variation of Precipitation

The SPI values and Hanning's low-pass filter of order 2 values applied to the chronological precipitation series of six stations of the KRW are presented in Table 2. Figure 5 shows an alternation of wet, normal and dry periods of which the amplitude varies according to the station. The period from 1961 until the end of 1970 was humid for the Kara, Niamtougou, Pagouda and Guérin-Kouka stations, and this continued until the beginning of the 1980s for the Alédjo-Kpéwa station. Takpamba's station stands out with a precipitation deficit that persisted until the beginning of the 1990s. A return to normal precipitation was observed after the 1990s and until 2011 at the Kara, Niamtougou and Pagouda stations. During the last decade, a decrease in precipitation was significant at most of the stations apart from Guérin-Kouka and Takpamba, which recorded an increase in precipitation with positive SPI values reaching +2.5. The return of a rise in rainfall at these stations was also noticed by some authors [52,77].

Two tendencies emerged when analyzing the SPI values. The stations located at higher altitudes, upstream from the KRW (Kara, Niamtougou, Pagouda and Alédjo-Kpéwa) are subject to a tendency of decreasing precipitation while those located at lower altitudes in the downstream portion (Guérin-Kouka and Takpamba) experience a tendency of increasing precipitation, even if the average annual rainfall is lower. The decrease in precipitation at the stations located upstream was also noted by [77,78]. Despite the long drought that marked the precipitation regime of the savannah region in extreme northern Togo (Mango and Dapaong station) since the 1970s, [79] showed that the region has been affected by increasingly more frequent exceptional rainfall events since the 1990s. Analysis of extreme climatic events in the Oti watershed in northern Togo suggest rising rates of total precipitation of between 1% and 16% with a rise of the rainfall level of about 13.89 mm [80]. The proximity of stations in the savannah region (Guérin-Kouka and Takpamba) is in agreement with the previous results. The periods 1998–2020 and 1993–2020, respectively, correspond to the wet periods at the Guérin-Kouka and Takpamba stations, as defined by [79] in the savannah region. This climate variability which induced a decrease in precipitation is due to the disorganization of seasons, which is potentially useful for agriculture [79]. Noting a significant effect on the yields of grain cultures, [46] suggested measures to adapt to the change, such as the use of seeds that are tolerant to drought, low-cost irrigation practices, diversification of cultures and the application of agroecological practices for sustainable agricultural production in northern Togo.

Table 2. Alternation of different phases and breaks detected within the precipitation series recorded at the measuring stations.

Stations	Periodic Trend within the Series			Breaks		
	Wet Period	Normal Period	Dry Period	Pettitt	Lee and Heghinian	Hubert
Kara	1961–1980	1989–2012	1981–1988 2013–2020	-	1963	-
Niamtougou	1961–1973	1993–2020	1974–1992	-	1972	1972
Pagouda	1961–1976 1994–2011	2012–2020	1977–1993	-	1965	1965

Alédjo-Kpéwa	1961–1982	1983–1999	2000–2020	2003	2003	1977; 1981; 2003
Guérin-Kouka	1998–2020	1961–1972	1973–1997	1997	1997	1997
Takpamba	1993–2020	-	1961–1992	1992	1992	1992

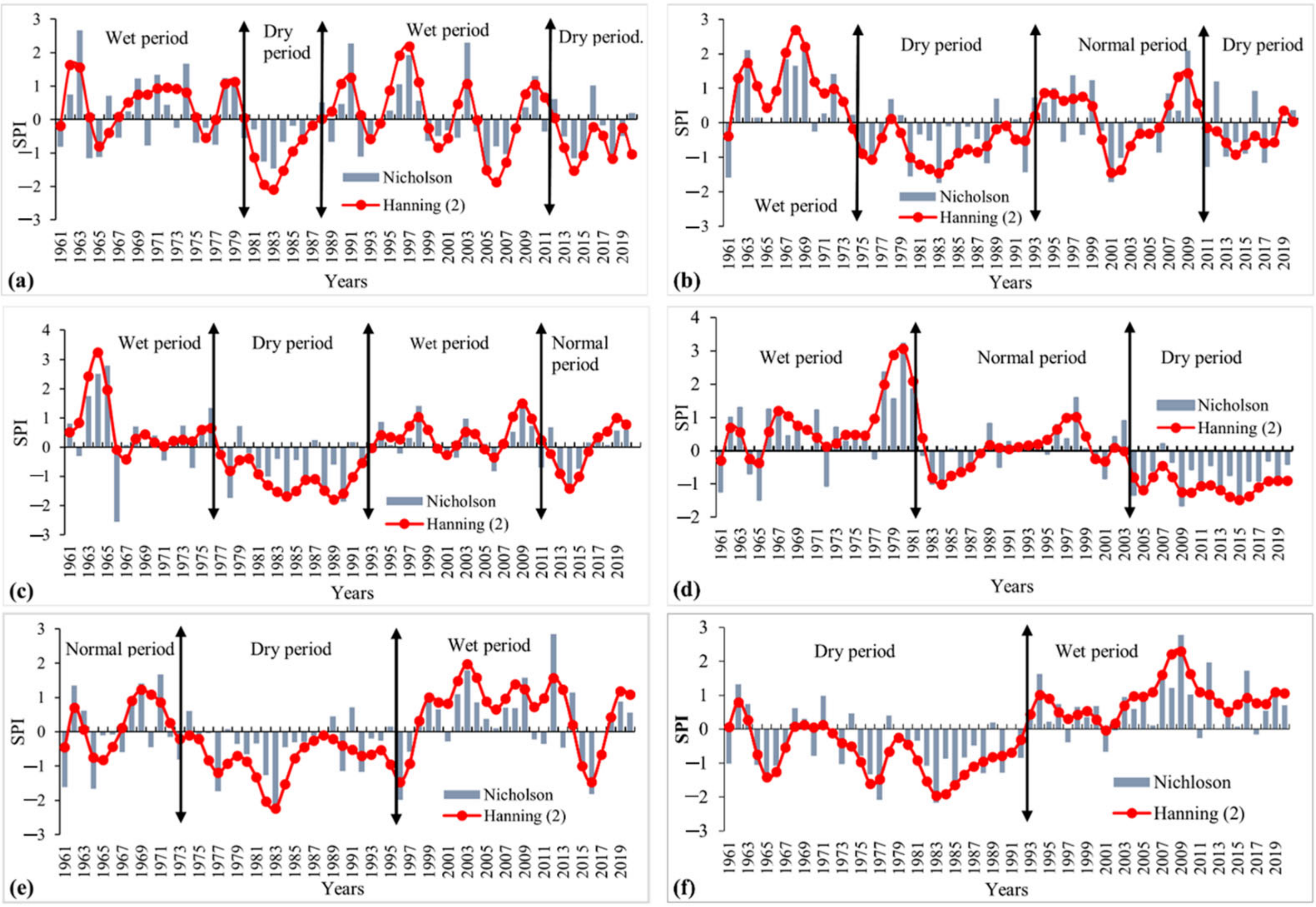

Figure 5. Nicholson's index and Hanning's low-pass filter of 2 applied to the KRW stations: (**a**) Kara; (**b**) Niamtougou; (**c**) Pagouda; (**d**) Alédjo-Kpéwa; (**e**) Guérin-Kouka and (**f**) Takpamba

The results produced by the spatial interpolation of precipitation over the watershed are presented in Figure 6. The repartition of isohyet curves for the six decades show contrasting precipitation temporal variability.

The period 1961–1970 (Figure 6(a)) was humid with maximum values at the Niamtougou and Alédjo-Kpéwa stations and the emergence of 1500 mm isohyets. Minimum values are observed in the downstream part of the watershed with 1200 and 1100 mm isohyets. This contrast can be explained by the influence of the watershed's geomorphology. According to Badjana et al. [45], the Dahomeyides mountain range, extending through the watershed, interrupts the trade winds coming from the southwest and promotes the formation of clouds.

The decade 1971–1980 (Figure 6(b)) experienced a decrease in precipitation at the Takpamba, Niamtougou (disappearance of the 1500 mm isohyet), Kara and Pagouda stations, but the Alédjo-Kpéwa station, located in the southern part of the watershed, recorded rainfall up to 1600 mm.

A general decrease in precipitation was observed during the decade 1981–1990 (Figure 6(c)) at all stations. We notice the appearance of the 1100 mm isohyet and the migration of the 1200 and 1300 mm isohyets to the northeast and southwest in the upstream part of the watershed.

The return to normal precipitation was observed during the decade 1991–2000 (Figure 6(d)). The consequence of this is the migration of the 1300 mm isohyet to the northwest, where the Guérin-Kouka and Takpamba stations are located, and the reappearance of the 1400 mm isohyet.

A slight decrease in precipitation was observed during the decade 2001–2010 (Figure 6(e)) at the Alédjo-Kpéwa, Kara, Niamtougou and Pagouda stations. This slight decrease was not observed at the Takpamba and Guérin-Kouka stations.

During the decade 2011–2020 (Figure 6(f)), a general decrease in precipitation in the watershed occurred but remained moderate in the north while it was accentuated in the south and center of the basin.

The spatial distribution in precipitation over the watershed thereby confirms the results obtained by studying the temporal variations, with the disappearance of the 1500 and 1400 mm isohyets at the watershed's scale during the two last decades. This spatiotemporal variation of precipitation was due to the drought that occurred in 1970 in the Sahelian countries, which continues in the southern countries [6]. The appearance of the 1300 mm isohyet in the upstream portion of the basin is the consequence of a return to normal precipitation during the decade 1991–2000 (Figure 6(d)). During the last two decades, [81] observed a slight phase of increased rainfall in northern Ghana, the magnitude of which is inferior to the phase of strong precipitation during the 1950s and 1960s. This situation can be described as an improvement even if the rainfall levels are not comparable to those of the 1950s and 1960s.

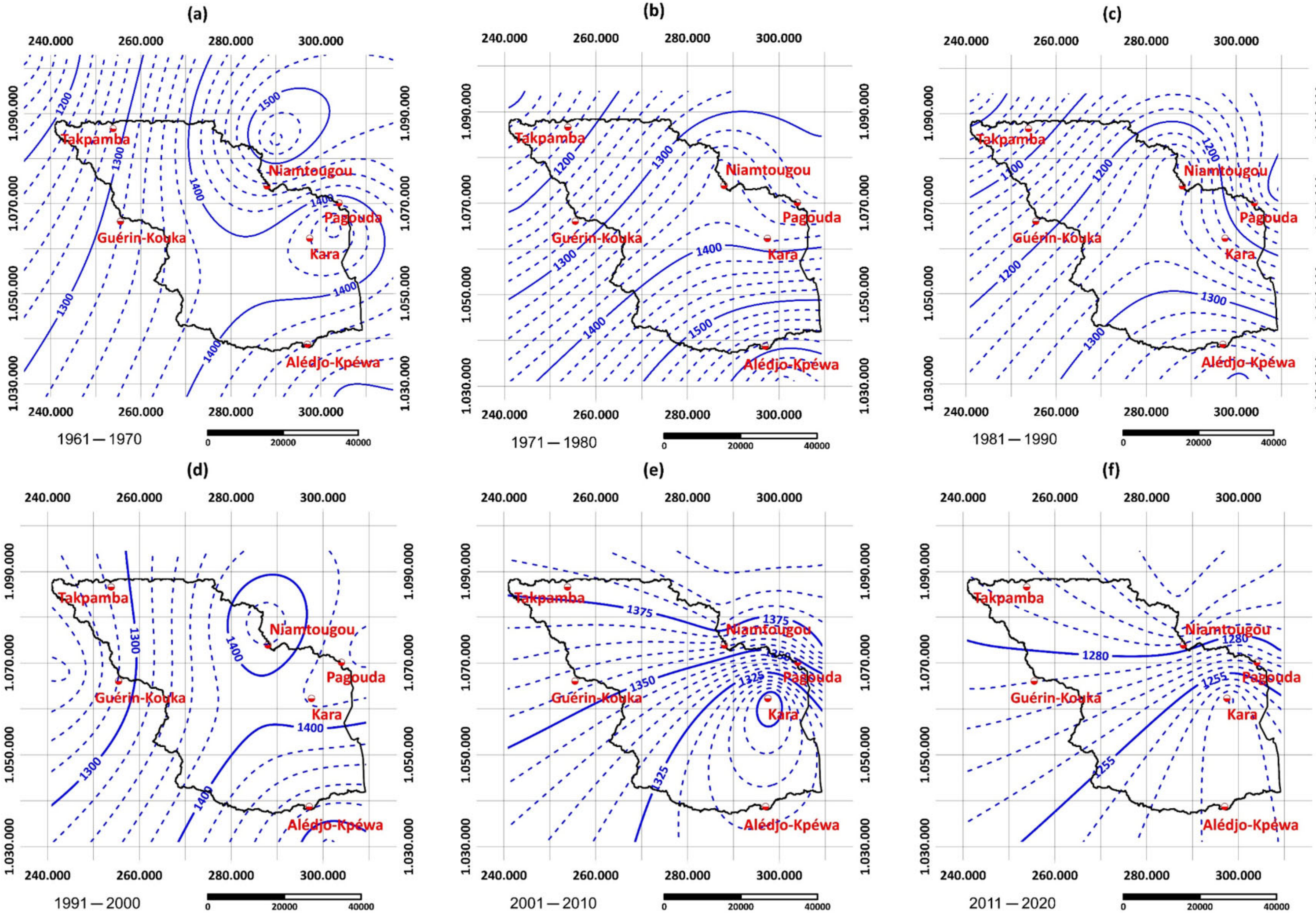

Figure 6. Spatial and temporal variation of decadal precipitation over the Kara River watershed during 1961 to 2020: (**a**) 1961–1970; (**b**) 1971–1980; (**c**) 1981–1990; (**d**) 1991–2000; (**e**) 2001–2010; (**f**) 2011–2020. The isohyets are represented by blue lines (the difference in precipitation levels between two isohyets varies according to the map).

4.2. Detection of Climatic Breaks

Several statistical break tests were applied to the different chronological precipitation series of each of the stations (Table 2). The Pettitt test shows no break at the Kara, Niamtougou and Pagouda stations but indicates a break for 2003, 1997 and 1992 at the Alédjo-Kpéwa, Guérin-Kouka and Takpamba stations, respectively. The Bayesian method of Lee and Heghinian shows breaks for 1963, 1965, 1972, 1997, 1992 and 2003 at the Kara, Niamtougou, Pagouda, Alédjo-Kpéwa, Guérin-Kouka and Takpamba stations, respectively. The Hubert segmentation shows no break at the Kara, Guérin-Kouka and Takpamba stations. Using this method, only the Alédjo-Kpéwa station recorded three breaks, in 1977, 1981 and 2003. The Kara and Pagouda stations recorded early breaks in 1963 and 1965 in opposition to Alédjo-Kpéwa station, which recorded a late break in 2003.

The various breaks that were calculated with the different tests are due to the statistical characteristics of the series which, according to [55], are normality, stationarity and non-autocorrelation:

- The more normal the series, the less probable the break; the non-observation of a break means normal behavior of the series and good autocorrelation.
- The methods for computing breaks do not produce the same response elements when considering the stationary nature of the series [55]. The Pettitt test is only valid for abrupt breaks and is invalid for continuous breaks [14].

As a general rule, the existence of a break in a series of hydrometeorological data indicates a sudden modification of the average in the series. Consequently, it is equivalent to a sudden temporal variability, hence the need to use various methods of break detection to characterize this modification within series and better discern climate variability at the considered stations.

The breaks occurred during 1963 to 2003. These break dates agree with values determined in the west African subregion [6,82–85]. The rainfall rates after these breaks varied from one station to another. At the Kara, Niamtougou, Pagouda and Alédjo-Kpéwa stations, the observed rates of precipitation decrease are about −12.5%, −13.2%, −23%, and −13.8%, respectively. At the Guérin-Kouka and Takpamba stations, precipitation increase of 12% and 27.3% were calculated. These results confirm the tendencies observed with the Nicholson method and Hanning's low-pass filter of order 2 used earlier.

4.3. Long-Term Tendencies of Precipitation

The results of the Mann–Kendall and the Sen tests applied to the interannual precipitation records of the six stations considered are presented in Table 3. The tendency is non-significant at the Kara, Niamtougou, Pagouda, and Guérin-Kouka stations as the corresponding p-value is superior to the level of significance $\alpha = 0.05$. These results support those of [47] who analyzed the temporal evolution of precipitation and temperature and their impact on cereal products in northern Togo. Significant statistical tendencies are observed at the Alédjo-Kpéwa and Takpamba stations (p-value < 0.05). The value of the S parameter is less than zero for the Alédjo-Kpéwa station, indicating a monotonous decreasing tendency within the series. On the contrary, the S parameter is more than zero at the Takpamba station, thus indicating a monotonous increasing tendency at this station. The amplitude of the reduction in the precipitation levels is −6.59 mm at the Alédjo-Kpéwa station, located in the more elevated upstream portion of the watershed. The level is rising by +6.83 mm at the Takpamba station, located in downstream portion of the watershed at a low altitude.

Table 3. Results of the Mann–Kendall and Sen tests.

Parameters	Kara	Niamtougou	Pagouda	Alédjo-Kpéwa	Guérin-Kouka	Takpamba
Rate of Kendall	−0.052	−0.13	−0.022	−0.30	0.11	0.31
S	−92	−222	−38	−536	266	556
p-value	0.56	0.16	0.81	0.6×10^{-3}	0.092	0.2×10^{-3}
Alpha	0.05	0.05	0.05	0.05	0.05	0.05
Tendency	No	No	No	Yes	No	Yes
Slope of Sen	−1.04	−2.3	−0.30	−6.59	2.24	6.83

Figure 7 illustrates the tendencies of the series computed with the ITA method. For the Kara station, we observe a non-monotonous positive tendency. A non-monotonous negative tendency is noted at the Niamtougou and Pagouda stations. The Alédjo-Kpéwa station records a monotonous negative tendency and, finally, the Guérin-Kouka and Takpamba stations show a monotonous positive tendency. A good interpretation of the annual rainfall requires their classification into three categories [35]: weak, average and strong. For example, for the Pagouda station (Figure 7(c)), weak rainfall tended toward increase in the second half of the series (1991–2003) as compared to the first half of the series (1961–1990), average rainfall did not present any tendency and strong rainfall had a tendency to decrease during the first half (1961–1990).

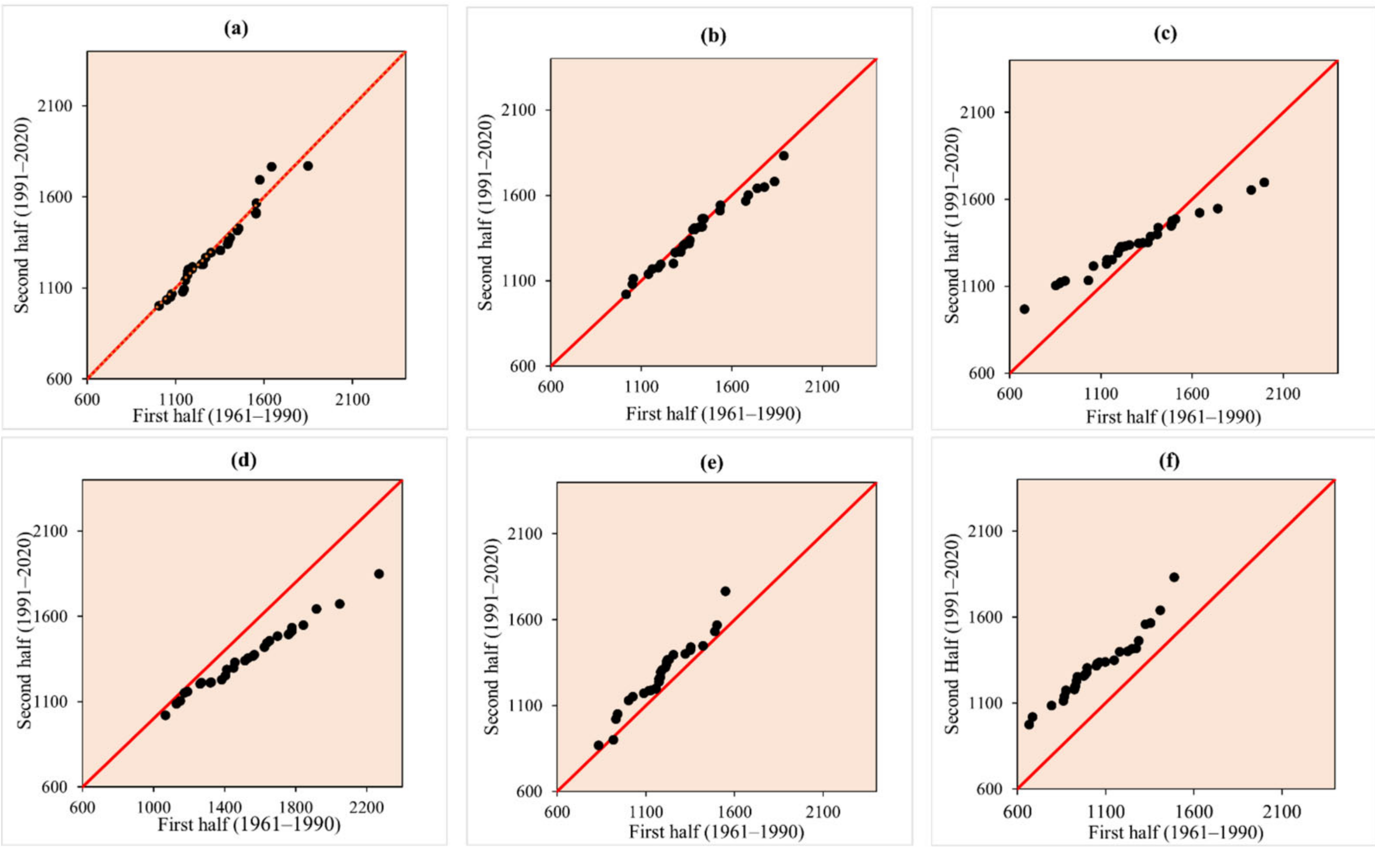

Figure 7. Results of the ITA method applied to the six stations in the Kara River watershed: (**a**) Kara; (**b**) Niamtougou; (**c**) Pagouda; (**d**) Alédjo–Kpéwa; (**e**) Guérin–Kouka; (**f**) Takpamba.

The results of the ITA method and the Mann–Kendall method are partially comparable. The tendencies found with the Mann–Kendall method have been confirmed by the ITA method, in particular at the Alédjo-Kpéwa and Takpamba stations. Concomitantly, in opposition to the Mann–Kendall method, the ITA method points out tendencies within the Kara, Niamtougou and Pagouda station series. According to Şen [35], the segmentation into three categories (weak, average and strong) provides detailed information about the structure of the internal tendency of the series considered. Other authors, who used the ITA method in other regions, confirmed that the method is more adapted to detect tendencies within the series [28,37,38]. The results obtained with the ITA method are important because they enable better comprehension of the hydroclimatic context and provide elements for water resource management [28].

The increased rainfall at the Guérin-Kouka and Takpamba stations during the 1961 to 2020 period (Table 3) indicates a return to normal precipitation at the watershed's scale. This confirms the results found earlier. The same observations were made by [86], who analyzed the climatic tendency in the Volta watershed during the period 1981–2010. These authors indeed observed a positive tendency in the precipitation of the Sahelian zone of the western part of Africa, which would indicate the establishment of a wet period. It could persist in time. The different results show that the tendency of increasing rainfall in the downstream part of the watershed of Kara is rather regionalized.

4.4. Consequences of the Climatic Variability on the Watershed's Water Resources

The climatic context is the principal factor of the spatiotemporal variability of groundwater recharge. Precipitation is the climatic factor that affects it the most [87]. Table 4 summarizes the evolution of the water balance parameters at the studied stations before and after the breaks. The tendency observed regarding the spatiotemporal variability of precipitation is also observed for aquifer recharge. Indeed, an increase in the recharge is observed at the Guérin-Kouka (+2%) and Takpamba (+16%) stations, and a decrease at the Kara (−15%), Niamtougou (−7%), Pagouda (−2%) and Alédjo-Kpéwa (−73%) stations. These results are similar to those obtained in studies carried out in analogous conditions. In the square degree of Grand Lahou in southwest Côte d'Ivoire, [88] observed a decrease in aquifer recharge at the Gagnoa (−80.5%) and Sassandra (−66%) stations. Results reported in [89] also showed the influence of precipitation changes on the recharge of aquifers in the Bandama watershed (northern Côte d'Ivoire), where the authors noted a 42.63% decrease at the Sirasso weather station and 72% at the Dikodougou weather station.

Table 4. Water balance parameters before and after the dates of break at the six KRW stations.

Water Balance Parameters	**Kara**		**Niamtougou**		**Pagouda**		**Alédjo-Kpéwa**		**Guérin-Kouka**		**Takpamba**	
	Break = 1963		Break = 1972		Break = 1965		Break = 1977		Break = 1997		Break = 1992	
	Before	After	Before	Before	Before	After	Before	After	Before	After	Before	After
Rainfall (mm·y^{-1})	1480	1294	1553	1607	1607	1277	1607	1385	1191	1334	1049	1335
PET (mm·y^{-1})	1689	1862	1681	1764	1764	1751	1764	1563	1757	2007	2144	2532
ETa (mm·y^{-1})	944	952	973	975	975	909	975	972	904	1031	869	1100
Excedent (R-ETa) (mm·y^{-1})	536	342	580	632	632	368	632	413	287	303	180	235
Runoff (mm·y^{-1})	379	208	442	445	445	226	445	363	182	196	84	124
Effective Infiltration (mm·y^{-1})	157	134	138	187	187	142	187	50	105	107	96	111

To specify the impact of climatic fluctuations on the flow of the Kara River, two chronological series of hydrometric data of the Kara River (Kara and Kpésside stations) were subjected to statistical break detection tests. The break appeared in 1974 (Pettitt test) at the Kara station (Figure 8a).

The average flow of the Kara River dropped from 23.63 m^3·s^{-1} before the break to 15.6 m^3·s^{-1} after the break, meaning a 34% decrease in flow during the period 1954–1990. At the Kpésside station (Figure 8b), only the Bayesian method of Lee and Heghinian detected a break in 1972. The flow of the Kara River dropped from 43.20 m^3·s^{-1} before the break to 28.11 m^3·s^{-1} after the break, representing a rate of decrease of 35%. Another report [90] also observed a deficit of 43% in the Mono-Couffo watershed, located between Togo and Benin, during the period 1961 to 2000. According to these authors, this diminution was mainly due to a precipitation deficit but also to strong evapotranspiration and anthropogenic effects.

The flow regime of the Kara River clearly indicates a deficit due to the decrease in the precipitation regime observed in the 1970s over Africa's western region and, more particularly, the KRW. The dry-off coefficients computed for the Kara River and the water volumes mobilized by the aquifers are compiled in Table 5.

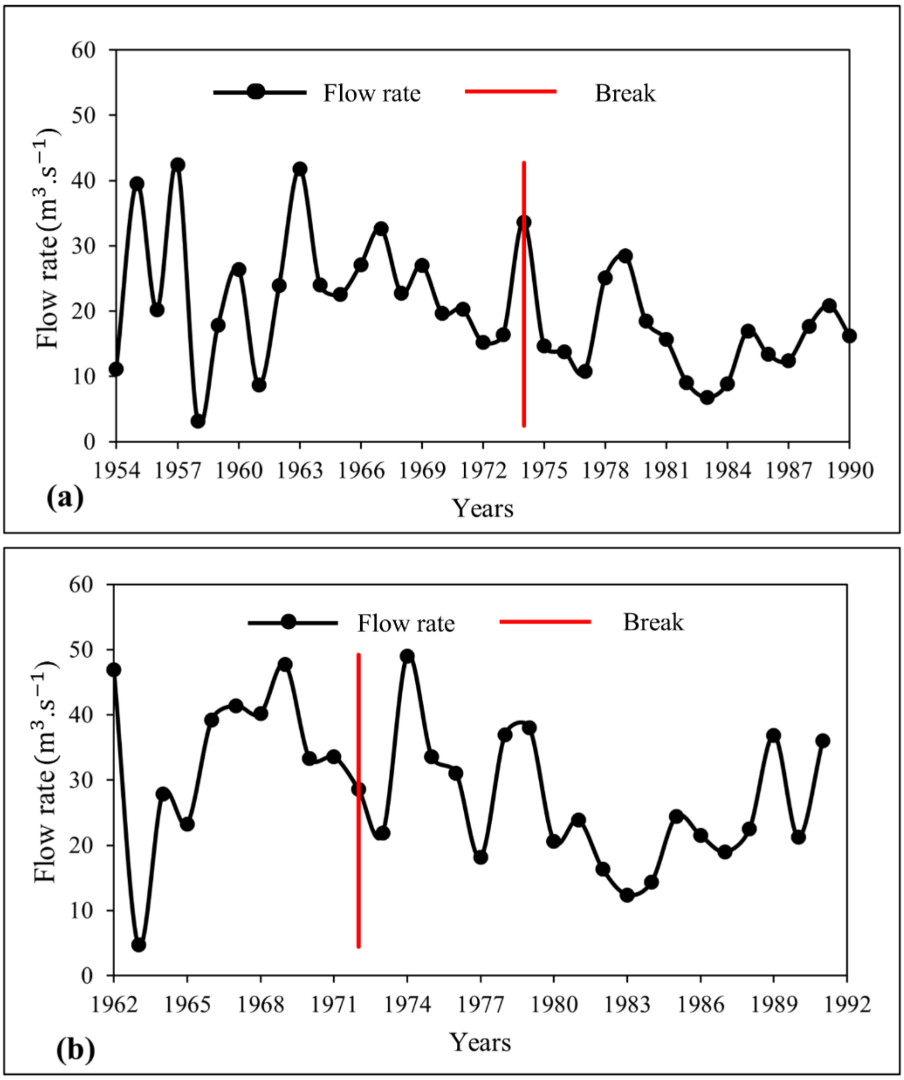

Figure 8. Interannual variation of flow at the Kara (**a**) and Kpéssidè (**b**) hydrological stations. The red line corresponds to years for which a statistical break has been computed.

Table 5. Results of the calculation of the recession coefficients and the water volumes mobilized by the aquifers before and after the break dates.

Stations	Period	Recession Coefficient (day^{-1})	Rate of Increase (%)	Water Volume Mobilized (km^3)	Rate of Decrease (%)	Recession Duration (day)
Kara	1954–1974	2.8 × 10^{-2}	25	0.32	22	36
	1975–1990	3.5 × 10^{-2}		0.25		29
Kpéssidè	1962–1972	3.1 × 10^{-2}	10	0.47	36	32
	1973–1991	3.4 × 10^{-2}		0.3		29

The evolution of the recession coefficients at the Kara hydrometric station during the different periods (Figure 9a) shows that the recession coefficient varies between 2.0 × 10^{-2} and 3.6 × 10^{-2} day^{-1} before the year of break with an average of 2.8 × 10^{-2} day^{-1} (inverse of 36 days). After the break, the values are between 2.1 × 10^{-2} and 4.8 × 10^{-2} day^{-1} with an average of 3.5 × 10^{-2} day^{-1} (inverse of 29 days). At the Kpéssidè station (Figure 9b), the recession coefficient values are between 1.9 × 10^{-2} and 4.3 × 10^{-2} day^{-1} with an average of 3.1 × 10^{-2} day^{-1} (inverse of 32 days) before the break and between 2.6 × 10^{-2} and 4.1 × 10^{-2} day^{-1} with an average of 3.4 × 10^{-2} day^{-1} (inverse of 29 days) after the break.

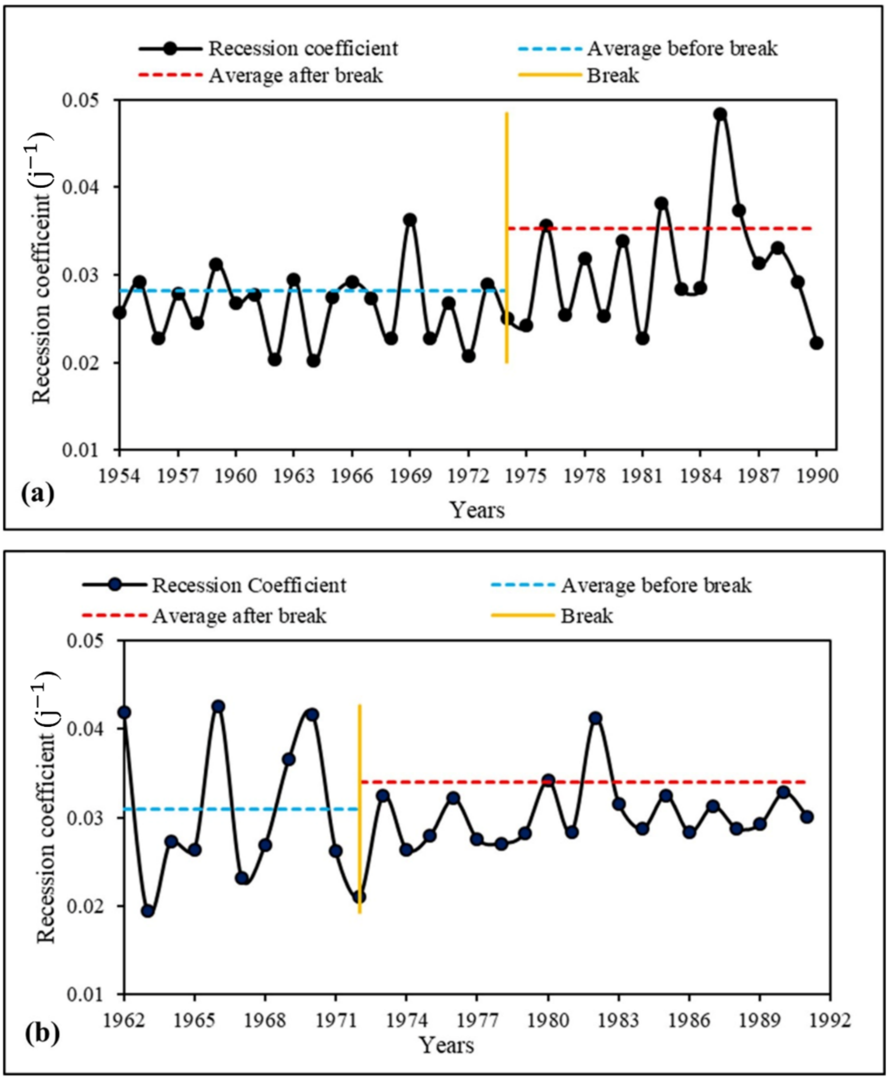

Figure 9. Variation of the dry-off coefficient at the Kara (**a**) and Kpéssidè (**b**) stations.

At the Kara station (Figure 10a), the average annual water volumes mobilized by the aquifers vary between 0.09 and 0.56 $km^3 \cdot yr^{-1}$ before the break with an annual average of 0.32 $km^3 \cdot yr^{-1}$. After the break, these values vary from 0.08 to 0.43 $km^3 \cdot yr^{-1}$ with an annual average of 0.25 $km^3 \cdot yr^{-1}$. The water volume mobilized by the aquifers thus fell by 22% after the climatic break. At the Kpéssidè station (Figure 10b), the water volume mobilized fluctuates between 0.04 and 0.9 $km^3 \cdot yr^{-1}$ before the break with an annual average of 0.47 $km^3 \cdot yr^{-1}$. After the break, the volume varies between 0.03 and 0.52 $km^3 \cdot yr^{-1}$ with an annual average of 0.3 $km^3 \cdot yr^{-1}$. The decline rate is thus about 36%.

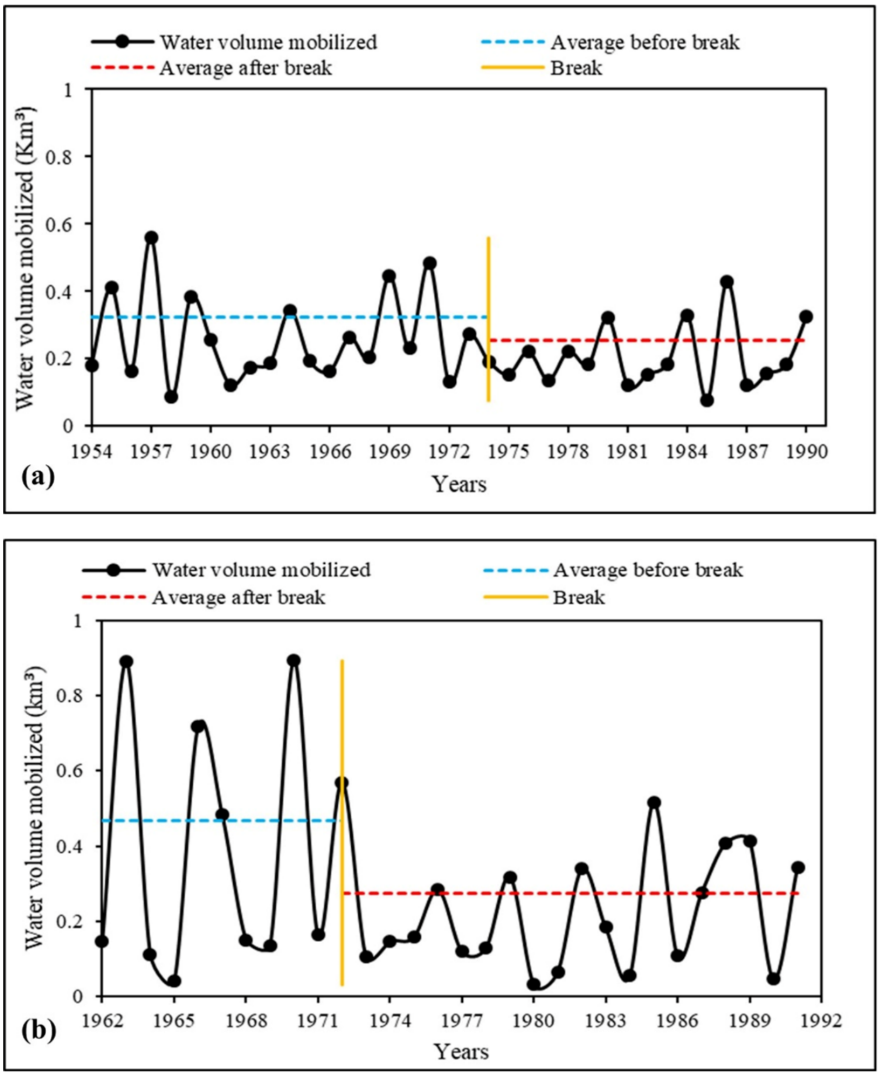

Figure 10. Variation of the water volume mobilized by the aquifers at the Kara (**a**) and Kpéssidè (**b**) stations.

The results show a 25% and 10% increase in the recession coefficient after the break dates at the Kara and Kpéssidè stations, respectively, and a shortening of the dry-off time by 8 days at Kara and 3 days at Kpéssidè (Table 5). Inversely, a diminution of the water volumes mobilized by the aquifers of the KRW was observed. The decreases are 22% and 36% at Kara and Kpéssidè, respectively. The recession coefficient is proportional to the drainage rate of the aquifer and increases in times of drought [91]. In this study, the increase in the recession coefficient indicates rapid drainage of the aquifers.

The values of the recession coefficient agree with those found in certain regions of western Africa [65,74,75,90,91]. These authors observed an increase in the recession coefficient with a decrease in the volume drained by the aquifers, which is partially due to the decrease in precipitation observed at the end of the 1960s and the beginning of the 1970s. The impoverishment of the base flow is due to a reduction in the water volume within the aquifers which, in principle, supplies the rivers during the dry-off phase [75]. Using this methodological approach, other authors [73–75,89,91] also showed the same decrease in water volumes mobilized by the aquifers at other localities.

5. Conclusions

Hydroclimatic functioning within the Kara River watershed in northern Togo was studied, based on classical statistics described in the literature. A mixed spatiotemporal variability of rainfall levels was highlighted with an alternation of wet, normal and dry periods. The spatial analysis revealed a return to normal precipitation in the watershed during the decade 1991–2000. Overall, the effect of the last drought during the 1970s was felt longer for the stations located in the upstream portion of the watershed (Kara, Niamtougou, Alédjo-Kpéwa and Pagouda) in contrast to the downstream stations (Guérin-Kouka and Takpamba), where an increase in rainfall amount was observed sooner. This tendency was confirmed by the Mann–Kendall test, the Sen test and the ITA test. The last method was adapted more to the detection of changes in tendency within hydrometeorological series than the other two. The recharge rate of the aquifers and the flow regime of the surface waters mimicked the climatic tendency prevailing in the watershed. The recharge decreased in the upstream part and increased in the downstream part of the watershed. Then, during dry periods, the aquifer contribution to the Kara River base flow was smaller and the recession coefficients had increased.

Given the climatic variability prevailing in the watershed of the Kara River, special attention has to be drawn to the sustainable management of the water resource and related activities such as agriculture and livestock production, which are performed by more than half of the population living within the area studied. Measures and adaptation methods could be considered for the agricultural sector, as a large part of the food consumed in sub-Saharan Africa is produced by small farmers. These results demonstrate the importance, in Togo and elsewhere worldwide, for developing and managing long-term climate and hydrometric monitoring networks. Indeed, the hydrometric network used for this work is no longer active, while the climatic conditions are likely to evolve in the coming years given the context of climate change that we are facing. The spatially heterogeneous reactivity of the hydrosystem studied shows that some sectors are more vulnerable than others to drought episodes. For these areas, as a priority, it is necessary to anticipate possible future climate crises.

Since precipitation is the only source for the supply of water to the aquifers, a study based on isotope hydrology could provide more precision on the origin of the rainwater, help to define the main recharge zones and enable a better understanding of the recharge modes for aquifers in the KRW. While knowledge of aquifer recharge and the quantitative approach proposed within this study are essential for management, a qualitative characterization of the surface water and groundwater resources would complete this dataset. Complementary work is thus ongoing—on one hand to ensure good water quality for human consumption and, on the other hand, to specify the flowpaths within the aquifer.

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References

1. Hughes, A.; Mansour, M.; Ward, R.; Kieboom, N.; Allen, S.; Seccombe, D.; Charlton, M.; Prudhomme, C. The impact of climate change on groundwater recharge: National-scale assessment for the British mainland. *J. Hydrol.* **2021**, *598*, 126336. https://doi.org/10.1016/j.jhydrol.2021.126336.
2. Raposo, J.R.; Dafonte, J.; Molinero, J. Assessing the impact of future climate change on groundwater recharge in Galicia-Costa, Spain. *Hydrogeol. J.* **2013**, *21*, 459–479.
3. Urama, K.C.; Ozor, N. Impacts of climate change on water resources in Africa: The Role of Adaptation. Climate change and water ressources in Africa. *Afr. Technol. Policy Stud. Netw.* **2010**, *29*, 1–29.
4. Döll, P. Vulnerability to the impact of climate change on renewable groundwater resources: A global-scale assessment. *Environ. Res. Lett.* **2009**, *4*, 035006.
5. Nicholson, S.E. Recent rainfull fluctuation in Africa and their relationship to past conditions over the continent. *Holocene* **1994**, *4*, 121–131. https://doi.org/10.1177/095968369400400202.
6. Paturel, J.E.; Servat, E.; Kouame, B.; Boyer, J.F.; Lubes, H.; Masson, J.M. Manifestations de la sécheresse en Afrique de l'Ouest non sahélienne. Cas de la Côte d'Ivoire, du Togo et du Bénin. *Sécheresse* **1995**, *6*, 95–102.
7. Servat, E.; Paturel, J.-E.; Lubès-Niel, H. La sécheresse gagne l'Afrique tropicale. *La Rech.* **1996**, *290*, 24–25.
8. Servat, E.; Paturel, J.E.; Kouame, B.; Travaglio, M.; Ouédraogo, M.; Boyer, O.; Lubes-Niel, H.; Fritsch, J.-M.; Masson, J.-M.; Marieu, B. Identification, Caractérisation et Conséquences D'une Variabilité Hydrologique en Afrique de l'Ouest et Centrale; In *Water Ressources Variability in Africa during the XXth Century*; International Association of Hydrological Sciences: Abidjan, Côte d'Ivoire, 1998; pp. 323–337.
9. Ouédraogo, M.; Servat, E.; Lubes-Niel, H.; Masson, J.M. Caractérisation d'une modification éventuelle de la relation pluie-débit autour des années 1970 en Afrique de l'Ouest et centrale non sahélienne, In *Water Ressources Variability in Africa during the XXth Century*; International Association of Hydrological Sciences : Abidjan, Côte d'Ivoire, 1998, *252*, 315–332.
10. Paturel, J.E.; Servat, E.; Delattre, M.O.; Lubes-Niel, H. Analyse de séries pluviométriques de longue durée en Afrique de l'Ouest et Centrale non sahélienne dans un contexte de variabilité climatique. *Hydrol. Sci. J.* **1998**, *43*, 937–946. https://doi.org/10.1080/02626669809492188.
11. Pettitt, A.N. A Non-Parametric Approach to the Change-Point Problem. *Appl. Stat.* **1979**, *28*, 126–135. https://doi.org/10.2307/2346729.
12. Bruneau, P.; Rassam, J.-C. Application of à Bayesian model to detect shifts in the mean of a series. *Hydrol. Sci. J.* **1983**, *28*, 341–354.
13. Hubert, P.; Servat, E.; Bendjoudi, H.; Lubes-Niel, H. La Procédure de Segmentation, Dix ans Après; In *Water Ressources Variabilty in Africa during the XXth Century*; IAHS: Abidjan, Côte d'Ivoire, 1998; pp. 267–273.
14. Bouba, L.; Sauvagnargues, S.; Gonne, B.; Ayral, P.-A.; Ombolo, A. Trends in rainfall and flood hazard in the Far North region of Cameroon. *Geo-Eco-Trop* **2017**, *41*, 339–358.
15. Zarenistanak, M.; Dhorde, A.G.; Kripalani, R.H. Trend analysis and change point detection of annual and seasonal precipitation and temperature series over southwest Iran. *J. Earth Syst. Sci.* **2014**, *123*, 281–295. https://doi.org/10.1007/s12040-013-0395-7.
16. Khosravi, H.; Sajedi-Hosseni, F.; Nasrollahi, M.; Gharechaei, H.R. Trend analysis and detection of precipitation fluctuations in arid and semi-arid regions. *Desert* **2017**, *22*, 77–84.
17. Lawin, E.A.; Hounguè, N.R.; Biaou, C.A.; Badou, D.F. Statistical Analysis of Recent and Future Rainfall and Temperature Variability in the Mono River Watershed (Benin, Togo). *Climate* **2019**, *7*, 8. https://doi.org/10.3390/cli7010008.
18. Nouaceur, Z.; Murarescu, O. Rainfall variability and trend analysis in west africa (Senegal, Mauritanie, Burkina). *Water* **2020**, *12*, 1754. https://doi.org/10.3390/w12061754.
19. Getahun, Y.S.; Li, M.-H.; Pun, I.-F. Trend and change-point detection analyses of rainfall and temperature over the Awash River basin of Ethiopia. *Heliyon* **2021**, *7*, e08024. https://doi.org/10.1016/j.heliyon.2021.e08024.
20. Yue, S.; Wang, C. The Mann-Kendall Test Modified by Effective Sample Size to Detect Trend in Serially Correlated Hydrological Series. *Water Resour. Manag.* **2004**, *18*, 201–218. https://doi.org/10.1023/B:WARM.0000043140.61082.60.
21. Kumar, S. Non-Parametric and Parametric Analysis of Runoff in Satluj River Basin, Himachal Pradesh, India. *Int. Lett. Chem. Phys. Astron.* **2015**, *54*, 15–36. https://doi.org/10.18052/www.scipress.com/ilcpa.54.15.
22. Some'e, B.; Ezani, A.; Tabari, H. Spatiotemporal trends of aridity index in arid and semi-arid regions of Iran. *Theor. Appl. Climatol.* **2013**, *111*, 149–160. https://doi.org/10.1007/s00704-012-0650-x.
23. Khatiwada, K.R.; Panthi, J.; Shrestha, M.L.; Nepal, S. Hydro-Climatic Variability in the Karnali River Basin of Nepal Himalaya. *Climate* **2016**, *4*, 17. https://doi.org/10.3390/cli4020017.
24. Koudahe, K.; Kayode, A.J.; Samson, A.O.; Adebola, A.A.; Djaman, K. Trend Analysis in Standardized Precipitation Index and Standardized Anomaly Index in the Context of Climate Change in Southern Togo. *Atmos. Clim. Sci.* **2017**, *7*, 401–423. https://doi.org/10.4236/acs.2017.74030.

25. Hu, M.; Sayama, T.; Try, S.; Takara, K.; Tanaka, K. Trend Analysis of Hydroclimatic Variables in the Kamo River Basin, Japan. *Water* **2019**, *11*, 1782. https://doi.org/10.3390/w11091782.
26. Daba, M.; Ayele, G.T.; You, S. Long-Term Homogeneity and Trends of Hydroclimatic Variables in Upper Awash River Basin, Ethiopia. *Adv. Meteorol.* **2020**, *2020*, 1–21. https://doi.org/10.1155/2020/8861959.
27. Braimah, M.; Asante, V.A.; Ahiataku, M.; Ansah, S.O.; Otu-Larbi, F.; Yahaya, B.; Ayabila, J.B. Seasonal Rainfall Variability over Southern Ghana. **2021**, *Preprints*, 202108. https://doi.org/10.20944/preprints202108.0150.v1.
28. Harka, A.E.; Jilo, N.B.; Behulu, F. Spatial-temporal rainfall trend and variability assessment in the Upper Wabe Shebelle River Basin, Ethiopia: Application of innovative trend analysis method. *J. Hydrol. Reg. Stud.* **2021**, *37*, 100915. https://doi.org/10.1016/j.ejrh.2021.100915.
29. Navatha, N.; Sreenivas, G.; Umareddy, R. Rainfall and Temperature Trends in Jagtial District of Telangana State. *Int. J. Environ. Clim. Change* **2021**, *11*, 47–59. https://doi.org/10.9734/IJECC/2021/v11i1130515.
30. Sarkar, A.; Saha, S.; Sarkar, D.; Mondal, P. Variability and trend analysis of the rainfall of the past 119 (1901-2019) years using statistical techniques: A case study of Uttar Dinajpur, India. *J. Clim. Change* **2021**, *7*, 49–61. https://doi.org/0.3233/JCC210011.
31. Tirkey, N.; Parhi, P.K.; Lohani, A.K.; Chandniha, S.K. Analysis of precipitation variability over Satluj Basin, Himachal Pradesh, India: 1901-2013. *J. Water Clim. Change* **2021**, *12*, 127–135. https://doi.org/10.2166/wcc.2020.136.
32. Mann, H.B. Nonparametric Tests Against Trend. *Econometrica* **1945**, *13*, 245.
33. Kendall, M.G. *Rank Correlation Methods*; Griffin: London, UK, 1975; ISBN 9780852641996.
34. Sen, K.P. Estimates of the regression coefficient based on Kendall's Tau. *J. Am. Assoc.* **1968**, *63*, 1379–1389.
35. Şen, Z. Innovative Trend Analysis Methodology. *J. Hydrol. Eng.* **2012**, *17*, 1042–1046. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556.
36. Şen, Z. Innovative trend significance test and applications. *Theor. Appl. Climatol.* **2015**, *127*, 939–947. https://doi.org/10.1007/s00704-015-1681-x.
37. Güçlü, Y.S. Multiple Şen-innovative trend analyses and partial Mann-Kendall test. *J. Hydrol.* **2018**, *566*, 685–704. https://doi.org/10.1016/j.jhydrol.2018.09.034.
38. Thapa, S.; Li, B.; Fu, D.-L.; Shi, X.; Tang, B.; Qi, H.; Wang, K. Trend analysis of climatic variables and their relation to snow cover and water availability in the Central Himalayas: A case study of Langtang Basin, Nepal. *Theor. Appl. Climatol.* **2020**, *140*, 3–4. https://doi.org/10.1007/s00704-020-03096-5.
39. Girma, A.; Qin, T.; Wang, H.; Yan, D.; Gedefaw, M.; Abiyu, A.; Batsuren, D. Study on recent trends of climate variability using innovative trend analysis: The Case of the upper Huai River Basin. *Pol. J. Environ. Stud.* **2020**, *29*, 2199–2210. https://doi.org/10.15244/pjoes/103448.
40. Besma, B.; Şen, Z.; Hamouda, B. Climate change impact on rainfall in north-eastern Algeria using innovative trend analyses (ITA). *Arab. J. Geosci.* **2021**, *14*, 511. https://doi.org/10.1007/s12517-021-06644-z.
41. Al-Gamal, S.A.; Sokona, Y.; Dodo, A.-K. Climatic changes and groundwater resources in Africa. *Int. J. Clim. Change Strateg. Manag.* **2009**, *1*, 133–145. https://doi.org/10.1108/17568690910955603.
42. Roudier, P.; Ducharne, A.; Feyen, L. Climate change impacts on runoff in West Africa: A review. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 2789–2801. https://doi.org/10.5194/hess-18-2789-2014.
43. Tirogo, J.; Jost, A.; Biaou, A.; Valdes-Lao, D.; Koussoubé, Y.; Ribstein, P. Climate variability and groundwater response: A case study in Burkina Faso (West Africa). *Water* **2016**, *8*, 171.
44. Agoh, C.F.; Lekadou, T.T.; Saley, M.B.; Gala, B.T.J.; Danumah, J.H.; Coffi, P.-M.J.; Koffi, Z.E.B.; Goula, B.T.A. Impact of Climate Variability on Water Resources: The Case of Marc Delorme-Cnra Station, Southeast of Ivory Coast. *J. Water Resour. Prot.* **2021**, *13*, 726–749. https://doi.org/10.4236/jwarp.2021.139038.
45. Badjana, M.H.; Wala, K.; Batawila, K.; Akpagana, K.; Edjaména, K.S. Analyse de la variabilité temporelle et spatiale des séries climatiques du nord du Togo entre 1960 et 2010. *Eur. Sci. J.* **2014**, *10*, 257–275.
46. Affaton, P. Le Bassin des Volta (Afrique de l'Ouest) : Une Marge Passive, D'âge Protérozoique Supérieur, Tectonisée au Panafricain (600 (+ ou−) 50 Ma). Ph.D. Thesis, Université d'Aix-Marseille III, Marseille, France, 1987, 496p.
47. Gadédjisso-Tossou, A.; Adjegan, K.I.; Kablan, A.K.M. Rainfall and Temperature Trend Analysis by Mann–Kendall Test and Significance for Rainfed Cereal Yields in Northern Togo. *Science* **2021**, *3*, 17. https://doi.org/10.3390/sci3010017.
48. Tairou, M.S. La Tectonique Tangentielle Panafricaine au Nord-Togo. Doctoral Dissertation, Université de Lomé, Lomé, Togo, 2006.
49. Lachassagne, P.; Wyns, R.; Dewandel, B. The fracture permeability of Hard Rock Aquifers is due neither to tectonics, nor to unloading, but to weathering processes: Weathering and permeability of Hard Rock Aquifers. *Terra Nova* **2011**, *23*, 145–161. https://doi.org/10.1111/j.1365-3121.2011.00998.x.
50. Musy, A.; Higy, C. *Hydrologie: Une Science de la Nature*; Presses Polytechniques et Universitaires Romandes: Vaud, Switzerland, 2004; p. 314.
51. Nicholson, S.E.; Kim, J.; Hoopingarner, J. *Atlas of African Rainfall and Its Interannual Variability*; Department of Meteorology, Florida State University Tallahassee: Floride, FL, USA, 1988; p. 237.
52. Oguntunde, P.G.; Abiodun, B.J.; Lischeid, G. Impacts of climate change on hydro-meteorological drought over the Volta Basin, West Africa. *Glob. Planet. Change* **2017**, *155*, 121–132. https://doi.org/10.1016/j.gloplacha.2017.07.003.

53. Assani, A.A. Analyse de la variabilité temporelle des précipitations (1916–1996) à Lubumbashi (Congo-Kinshasa) en relation avec certains indicateurs de la circulation atmosphérique (oscillation australe) et océanique (El Niño/La Niña). *Sci. Changements Planétaires/Sécheresse* **1999**, *10*, 245–252.
54. Lamb, P.J. Persistence of subsaharan drought. *Nature* **1982**, *299*, 46–47.
55. Lubes-Niel, H.; Masson, J.M.; Paturel, J.E.; Servat, E. Climatic variability and statistics. A similation approch for estimating power and robustness of tests of stationarity. *J. Water Sci.* **1998**, *11*, 383–408. https://doi.org/10.7202/705313ar.
56. *Khronostat*, version 1.0; Logiciel D'analyse Statistique de Séries Chronologiques, Développé Par l'Orstom UR 2-21; l'Ecole des Mines de Paris et l'UMR GBE de l'Université de Montpellier II: Montpellier, France, 1998. Available online: http://www.hydrosciences.org/index.php/2020/09/04/khronostat/ (accessed on 4 September 2020).
57. Machiwal, D.; Jha, M.K. *Hydrological Times Series Analysis: Theory and Practice*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2012; p. 315. https://doi.org/10.1007/978-94-007-1861-6_1.
58. Xiong, L.; Guo, S. Trend test and change-point detection for the annual discharge series of the Yangtze River at the Yichang hydrological station. *Hydrol. Sci. J.* **2004**, *49*, 99–112. https://doi.org/10.1623/hysj.49.1.99.53998.
59. Oguntunde, P.G.; Friesen, J.; van de Giesen, N.; Savenije, H.H.G. Hydroclimatology of the Volta River Basin in West Africa: Trends and variability from 1901 to 2002. *Phys. Chem. Earth* **2006**, *31*, 1180–1188. https://doi.org/10.1016/j.pce.2006.02.062.
60. Djaman, K.; Koudahe, K.; Ganyo, K.K. Trend Analysis in Annual and Monthly Pan Evaporation and Pan Coefficient in the Context of Climate Change in Togo. *J. Geosci. Environ. Prot.* **2017**, *5*, 41–56. https://doi.org/10.4236/gep.2017.512003.
61. Eshetu, M. Hydro-climatic Variability and Trend Analysis of Modjo River Watershed, Awash River Basin of Ethiopia. *J. Environ. Earth Sci.* **2021**, *11*, 38–48. https://doi.org/10.7176/jees/11-9-04.
62. Penman, H.L. Natural Evaporation from Open Water, Bare Soil and Grass. *Proc. R. Soc. Lond.* **1948**, *193*, 120–145. https://doi.org/10.1098/rspa.1948.0037.
63. Thornthwaite, C.W. An Approach toward a Rational Classification of Climate. *Geogr. Rev.* **1948**, *38*, 55–94. http://doi.org/10.2307/210739.
64. Turc, L. *Evaluation des Besoins en Eau Irrigation, Evaporation Potentielle*; Annales Agronomiques: Paris, France, 1961; pp. 13–49.
65. Assémian, A.E.; Kouame, K.F.; Djagoua, V.E.; Affian, K.; Jourda, J.P.J.; Adja, M.; Lasm, T.; Biemi, J. Impact of climatic variabilty on water ressources in a humid tropical climate. *J. Water Sci.* **2013**, *26*, 247–261. https://doi.org/10.7202/1018789ar.
66. Santoni, S.; Huneau, F.; Garel, E.; Celle-Jeanton, H. Multiple recharge processes to heterogeneous Mediterranean coastal aquifers and implications on recharge rates evolution in time. *J. Hydrol.* **2018**, *559*, 669–683. https://doi.org/10.1016/j.jhydrol.2018.02.068.
67. Kawoun, A.G.; Ahamide, B.; Chabi, A.; Ayena, A.; Adanddedji, F.; Vissin, E. Rainfall Variability and Impacts on Surface Water in the lower Ouémé Valley in South-East Bénin. *Int. J. Progress. Sci. Technol.* **2020**, *23*, 52–65.
68. Akpataku, K.V. Apports de L'hydrogéochimie et de L'hydrologie Isotopique à la Compréhension du Fonctionnement des Aquifères en Zones de Socle Dans la Région des Plateaux au Togo. Ph.D. Thesis, Université de Lomé, Lomé, Togo, 2018, 259p.
69. Faye, C.; Mendy, A. Climatic variability and hydrological impacts in case of the Gambiawatershed (Senegal). *Environ. Water Sci. Public Health Tertitorial Intellignece J.* **2018**, *2*, 54–66.
70. Lang, C.; Gille, E. A recession analysis method for low flow forecasting. *Norois* **2006**, *201*, 31–43. https://doi.org/10.4000/norois.1743.
71. Maillet, E. La vidange des 22eserve de 22eserves22s. *Ann. Des Ponts Et Chaussées Mémoires Et Doc.* **1906**, *21*, 218.
72. Castany, G. Courbes de tarissement et calcul des 22eserves régulatrices. *Gen. Assem. Berkeley Int. Assoc. Sci. Hydrol.* **1964**, *63*, 319–328.
73. Savané, I.; Coulibaly, K.M.; Gioan, P. Etude comparative de trois méthodes de calcul du coefficient de tarissement des cours d'eau. *Secheresse* **2003**, *14*, 37–42.
74. Goula, B.T.A.; Savane, I.; Konan, B.; Fadika, V.; Kouadio, G.B. Impact de la variabilité climatique sur les ressources hydriques des bassins de N'Zo et N'Zi en Côte d'Ivoire (Afrique tropicale humide). *VertigO* **2006**, *7, 1-12*. https://doi.org/10.4000/vertigo.2038.
75. Kouassi, A.M.; Kouamé, K.F.; Saley, M.B.; Biémi, J. Application du modèle de maillet à l'étude des impacts des changements climatiques sur les ressources en eau en Afrique de l'Ouest : Cas du bassin versant du N'zi-Bandama (Côte d'Ivoire). *J. Asian Sci. Res.* **2013**, *3*, 214–228.
76. Berhail, S. The impact of climate change on groundwater resources in northwestern Algeria. *Arab. J. Geosci.* **2019**, *12*, 770. https://doi.org/10.1007/s12517-019-4776-3.
77. Badjana, H.M.; Renard, B.; Helmschrot, J.; Edjamé, K.S.; Afouda, A.; Wala, K. Bayesian trend analysis in annual rainfall total, duration and maximum in the Kara River basin (West Africa). *J. Hydrol. Reg. Stud.* **2017**, *13*, 255–273. https://doi.org/10.1016/j.ejrh.2017.08.009.
78. Pilabina, S.; Yabi, I.; Kola, E. *Changements Climatiques et Sensibilité des Ressources en eau Dans le Bassin Versant de la Kara au Nord du Togo, Conference paper, XXXII ème Colloque International de l'AIC*: the Climatic change Variability and Climatic Risks, Thessaloniki, Grèce, 2019, 107-112.
79. Adéwi, E.; Badameli, K.M.S.; Dubreuil, V. Evolution des saisons des pluies potentiellement utiles au Togo de 1950 à 2000. *Climatologie* **2010**, *7*, 89–107.
80. Adjoussi, P. Analyse des extremes climatiques dans le bassin de l'Oti au nord Togo. *J. De La Rech. Sci. De L'université De Lomé* **2021**, *23*, 115–133.

81. Owusu, K. Rainfall changes in the savannah zone of northern Ghana 1961–2010. *Weather* **2018**, *73*, 46–50. https://doi.org/10.1002/wea.2999.
82. Doumouya, I.; Kamagaté, B.; Bamba, A.; Ouedraogo, M.; Ouattara, I.; Savané, I.; Goula, B.T.A.; Biémi, J. Impact de la variabilité climatique sur les ressources en eau et végétation du bassin versant du Bandama en milieu inetrtropical (Côte d'Ivoire). *Rev. Ivoir. Des Sci. Et Technol.* **2009**, *14*, 203–215.
83. Irié, G.R.; Soro, G.E.; Goula, B.T.A. Recent variations in space-time of rainfall settings and their impact on flow river Marahoué (Ivoiry Coast). *Larhyss J.* **2016**, *25*, 241–258.
84. Assémian, E.A.; Kanga, K.H.M.; Kouassi, K.; Yao, K.J.-J.; Koffi, B.E. Analyse des variations de la recharge des eaux souterraines du socle de Dimbokro, Zone tropicale humide du Centre-Est de la Côte d'Ivoire, face au changement climatique. *Rev. Ivoir. Des Sci. Et Technol.* **2018**, *31*, 84–107.
85. Gnamba, F.M.; Kpan, O.J.G.; Yapi, A.F.; Oga, M.S.Y. Rainfall variability from Kotiala region in the North of Côte d'Ivoire (West Africa). *Eur. Sci. J.* **2020**, *16*, 169–188. https://doi.org/10.19044/esj.2020.v16n33p169.
86. Darko, D.; Adjei, K.A.; Odai, S.N.; Obuobie, E.; Asmah, R.; Trolle, D. Recent climate trends for the Volta Basin in West Africa. *Weather* **2019**, *74*, S13–S22. https://doi.org/10.1002/wea.3303.
87. Amanambu, A.C.; Obarein, O.; Mossa, J.; Li, L.; Ayeni, S.S.; Balogun, O.; Oyebamiji, A.; Ochege, U.F. Groundwater System and Climate Change: Present Status and Future Considerations. *J. Hydrol.* **2020**, *589*, 125163. https://doi.org/10.1016/j.jhydrol.2020.125163.
88. Soro, T.D.; Soro, N.; Oga, Y.M.-S.; Lasm, T.; Soro, G.; Ahoussi, K.E.; Biémi, J. La variabilité climatique et son impact sur les ressources en eau dans le degré carré de Grand-Lahou (Sud-Ouest de la Côte d'Ivoire). *Physio-Géo. Géographie Phys. Et Environ.* **2011**, *5*, 55–73. https://doi.org/10.4000/physio-geo.1581.
89. Kamagaté, A.; Koffi, Y.B.; Kouassi, A.M.; Kouakou, B.D.; Seydou, D. Impact des évolutions climatiques sur les ressources en eau des pétits bassins en Afrique Sub-Saharienne : Application au bassin versant du Bandama à Tortiya (Nord Côte d'Ivoire). *Eur. Sci. J.* **2019**, *15*, 84–105. https://doi.org/10.19044/esj.2019.v15n9p84.
90. Amoussou, E.; Camberlin, P.; Mahé, G. Impact de la variabilité climatique et du barrage Nangbéto sur l'hydrologie du système Mono-Couffo (Afrique de l'Ouest). *Hydrol. Sci. J.* **2012**, *57*, 805–817. https://doi.org/10.1080/02626667.2011.643799.
91. Kouakou, E.; Koné, B.; N'Go, A.; Cissé, G.; Speranza, C.I.; Savané, I. Groundwater sensitivity to climate variability in the white Bandama basin, Ivory Coast. *SpringerPlus* **2014**, *3*, 226. https://doi.org/10.1186/2193-1801-3-226.