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Detection of Hydrologic Trends and Variability in Transboundary Cavally Basin (West Africa)

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Abstract In a context of climate change and decreasing water resources, knowledge of recent flow evolution is essential. The present study focuses on the analysis of trends and spatio-temporal evolution of the Cavally River flow. In this study, 8 hydrometric stations, including 6 on the main river (Flampleu, Ity, Toulepleu, Taï, Feté and Taté) and two tributaries (N'Cé and Niébé) of the Cavally River were selected based on the availability and quality of long-term data. Annual and monthly data from these stations cover the period from 1980 to 2016. Statistical methods and the Hanning low-pass filter are used to highlight the evolution of the annual mean discharge and the spatial distribution of the different hydrometric seasons over the period 1980-2016. Hanning low-pass filter, Mann-Kendall tests (Classic, Modified and Seasonal) and SNHT were applied to detect and analyze the significance of change over time. The results of the statistical tests and Hanning's low-pass filter show the seasonal and annual change in flows. Stations in the northern part of the basin generally had a long dry period from 1980 to 2010 and a wet period from 2011 to 2016 and those in the central part had a wet period from 1980 to 2005 and dry period from 2006 to 2016. Stations in the central part have alternating normal periods. The significant increase in runoff during the dry season and some months of the rainy season was the main reason for the increase in annual runoff due to the considerable contributions of these seasons to the total runoff volume in the Cavally basin. Based on the results of the SNHT test for detecting abrupt changes in the series, about 62% of the series show a significant break, of which 60% are ascending at the 5% to 1% significance level. All observed breaks are generally located between 2000 and 2013.

Keywords: *Cavally basin, change abrupt, flows, statistical methods, trend significant*

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1. Introduction

Water resource management is one of the major issues of the 21st century. Many phenomena, natural or anthropogenic, influence the resource and more particularly the water cycle [1]. Among them climate variability and human activities are the main drivers of changes in watershed hydrology [2,3]. The impact of flow fluctuation on the volume of available water can lead to many problems (drinking water supply, crop irrigation, or even energy production). Watercourses also play an important role in maintaining the proper functioning of ecosystems [4,5,6]. This need for water, related to ecosystems and anthropogenic activities, remains large or is growing. However, all West African countries have experienced a remarkable decline in runoff since 1960. According to [7-12] this decrease in runoff is linked to the decrease in rainfall that induced the great drought that Africa experienced. Then, according to [13] and [14], after the very long (1968-1995), very extensive (more than 6 million km² very affected) and very pronounced (from 10 to 40% decrease in rainfall depending on the location) dry episode that West Africa experienced, we are witnessing an undeniable recovery in rainfall in this area. In Côte d'Ivoire, the work of [15] and [16] show a recovery in the north and south of the country from 2000 and 2003 respectively. This rainfall recovery could suggest that West Africa has entered a new climatic phase in the last ten years, and therefore a new phase in runoff [17]. Given the close link between rainfall and runoff, the study of the recent evolution of runoff in West Africa is necessary. However, few and far between are the studies dealing with the recent stationarity of runoff, particularly the annual and seasonal average flows in Côte d'Ivoire. Particularly on the 30 000 km^2 of the transboundary basin of Cavally. The main objective of this study is to provide a holistic analysis of the recent trends observed in the flows of the Cavally basin. More specifically, this study aims to (i) examine the spatio-temporal changes in annual and monthly average runoff, (ii) identify the new distribution of the different hydrological seasons in the basin. Indeed, the analysis of recent changes in flows at the local (watershed) scale is useful to provide scientific knowledge for water resources management [18].

2. Materiel

2.1. Study Zone

The Cavally is a transboundary river (Ivory Coast, Guinea and Liberia), located between longitudes 8°36' and 6°48' West and latitudes 7°57'22" and 4°19'34" North (Figure 1). It originates from Guinea from the north of Mount Nimba at an altitude of 650m and empties into the Atlantic Ocean on the border between Liberia and Ivory Coast. It is 700 km long until its mouth, the basin of this river drains an area of 29,998 km², the bed of which serves as the natural border between Ivory Coast and Liberia in its middle and lower reaches. The basin is divided between Côte d'Ivoire (54%), Liberia (41%) and Guinea (5%).

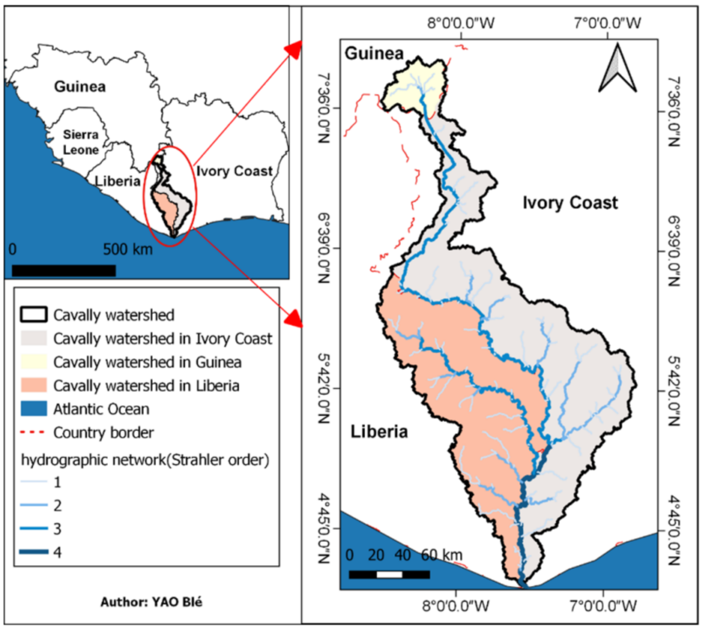

Figure 1. Geographical location of the Cavally river basin

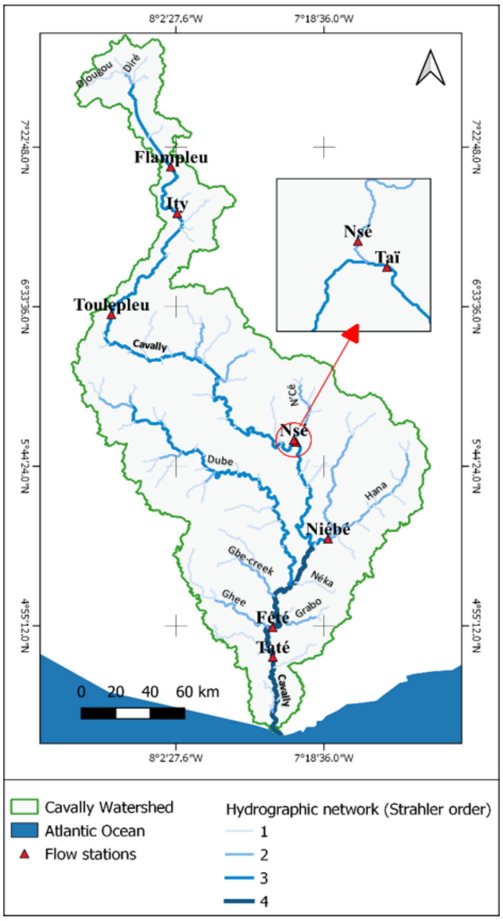

Figure 2. Geographical location of flows stations in Cavally watershed

2.2. Data

Historical hydrological data were collected from the hydraulic infrastructure division, Government of Cote d'Ivoire. In this study, the hydrological data include meaning the daily flow of the Cavally river. and its tributaries (Diré, Djougou, N'Cé, Hana, Dube, Néka, Gbe-creek, Grabo and Ghee). The data cover the period from 1980 to 2016. The selection was based on the long record of data, less missing records, and functionality, the geographical position of flow stations in the Cavally basin (Figure 2).

3. Methods

The subject of trend detection in hydrological data has received a lot of attention lately, especially in the context of climate change. However, the existence of dependencies (autocorrelation), short or long range, can adversely affect the results of a trend analysis [19]. In particular, Mann-Kendall's test [20,21] which is generally used to detect trends in climate data becomes highly biased in the presence of autocorrelation [19]. The cumulative monthly and annual rainfall as well as the monthly and annual average flow rate were used to perform the various tests.

3.1. Hanning's Low Pass Non-recursive Filter of Order 2

A better observation of inter-annual fluctuations is obtained by eliminating seasonal variations. The calculation of the weighted filter flow totals is performed using the equations recommended by [22]. According to this method, each term in the series is calculated by equation:

$$\begin{aligned} \mathbf{X_t} &= 0.06\mathbf{x_{t-2}} + 0.25\mathbf{x_{t-1}} + 0.38\mathbf{x_t} \\ &+ 0.25\mathbf{x_{t+1}} + 0.06\mathbf{x_{t+2}} \end{aligned} \tag{1}$$

with:

x_{t-2} et x_{t-1} totals of the observed flows of two terms immediately preceding the term x_t ;

x_{t+2} et x_{t+1} totals of the observed flows of two terms immediately following the term x_t ;

The weighted flow totals of the first two (X_1 et X_2) and the last two (X_{n-1} et X_{n-2}) terms of the series are calculated by means of equations 5, 6, 7 and 8 (n being the size from the series):

$$\mathbf{X}_1 = 0.54\mathbf{x}_1 + 0.46\mathbf{x}_2 \tag{2}$$

$$\mathbf{X}_2 = 0.25\mathbf{x}_1 + 0.50\mathbf{x}_2 + 0.25\mathbf{x}_3 \tag{3}$$

$$\mathbf{X_{n-1}} = 0.25\mathbf{x_{n-2}} + 0.50\mathbf{x_{n-1}} + 0.25\mathbf{x_n} \tag{4}$$

$$\mathbf{X_n} = 0.54\mathbf{x_n} + 0.46\mathbf{x_{n-1}} \tag{5}$$

To obtain a better visualization of the periods of shortfall and surplus flow, the averages downpour are centered and reduced by means of the equation ...:

$$\mathbf{Y_t} = \frac{(\mathbf{x_t} - \mathbf{m})}{\sigma} \tag{6}$$

m: is the mean of the series of weighted means and σ the standard deviation of the series of weighted moving averages.

3.2. Trend Detection Methods

3.2.1. Mann-Kendall's Classic Test

This test checks if there is a trend in the time series data. It is a non-parametric test robust to the influence of extremes and allows its application to biased variables [23]. More particularly, this nonparametric trend test is the result of an improvement of the test first studied by [20] then taken up by [21] and finally perfected by [24].

Mann-Kendall's test is based on the sign of the difference between the ranks of a time series. Given a time series of $X = (x_1, x_2 \ldots\ldots x_n)$, Mann-Kendall's statistics is given as:

$$\mathbf{S} = \sum_{\mathbf{i}=1}^{\mathbf{n}-1} \sum_{\mathbf{j}=\mathbf{i}+1}^{\mathbf{n}} \mathbf{a_{ij}} \tag{7}$$

Or:

$$\mathbf{a_{ij}} = \mathbf{sign}(\mathbf{x_j} - \mathbf{x_i}) = \mathbf{sign}(\mathbf{R_j} - \mathbf{R_i}) \tag{8}$$

$$= \begin{cases} 1\ \mathbf{si}\, \mathbf{x_j} > \mathbf{x_i} \\ 0\ \mathbf{si}\, \mathbf{x_j} = \mathbf{x_i} \\ -1\ \mathbf{si}\, \mathbf{x_j} < \mathbf{x_i} \end{cases} \tag{9}$$

and R_j, R_I are respectively, the ranks of the observations of the series. Under the hypothesis that the data are independent and identically distributed. [21], gives the mean and variance of the above S-test statistics:

$$\mathbf{E}(\mathbf{S}) = 0 \tag{10}$$

$$\mathbf{Var}(\mathbf{S}) = \frac{\mathbf{n}(\mathbf{n}-1)(2\mathbf{n}+5)}{18} \tag{11}$$

where **n** is the size of the series. The existence of equal observations in the series leads to a reduction in the variance of **S**, which becomes:

$$\begin{aligned} \mathbf{Var}(\mathbf{S}) &= \frac{\mathbf{n}(\mathbf{n}-1)(2\mathbf{n}+5)}{18} \\ &- \frac{\sum_{\mathbf{j}=1}^{\mathbf{m}} \mathbf{t_j}(\mathbf{t_j}-1)(2\mathbf{t_j}+5)}{18} \end{aligned} \tag{12}$$

where **m** is the number of groups of equal observations and **t j** is the number of equal observations in group **j**.

We can normalize statistics of the test to get a new **Z** test statistic:

$$\mathbf{Z} = \begin{cases} \dfrac{(\mathbf{S}-1)}{\sqrt{\mathbf{V}_0(\mathbf{S})}} & \mathbf{si}\ \mathbf{S} > 0 \\ 0 & \mathbf{si}\ \mathbf{S} = 0 \\ \dfrac{(\mathbf{S}+1)}{\sqrt{\mathbf{V}_0(\mathbf{S})}} & \mathbf{si}\ \mathbf{S} > 0 \end{cases} \tag{13}$$

A positive (or negative) value of Z indicates an ascending (or descending) trend and its significance is compared to the critical value α or significance threshold of the test.

3.2.2. Modified Mann-Kendall Test

The presence of autocorrelation in the data can seriously affect the power of statistical tests by overestimating the statistical significance of trends. This autocorrelation is usually generated by a cyclic recurrence in the evolution of the data reflecting a dependence on external phenomena (variation in recharging, application cycles). A complementary approach to the classic Mann-Kendall test is thus proposed in order to take into account this phenomenon of autocorrelation. The principle is based on a modification of Mann-Kendal's S test rather than modifying the data itself:

$$\mathbf{Var}_\rho(\mathbf{S}) = \gamma * \mathbf{Var}_{\rho=0}(\mathbf{S}) \tag{14}$$

where **γ** is a corrective factor applied to the variance.

Two methods are noted in the literature to estimate this corrective factor.

- [25] suggest correcting the Mann-Kendall test as follows:

$$\gamma = 1 + 2 * \frac{\rho_1^{\mathbf{n}+1} - \mathbf{n}\rho_1^2 + (\mathbf{n}-1)\rho_1}{\mathbf{n}(\rho_1 - 1)^2} \tag{15}$$

where $\boldsymbol{\rho_1}$ denotes the autocorrelation of order 1

- [26] propose an empirical formula specifically calculated to correct Mann-Kendall's statistics:

$$\begin{aligned} \gamma &= 1 + \frac{2}{\mathbf{n}(\mathbf{n}-1)(\mathbf{n}-2)\rho_1} \\ &\times \sum_{\mathbf{k}=1}^{\mathbf{n}-1} (\mathbf{n}-\mathbf{k})(\mathbf{n}-\mathbf{k}-1)(\mathbf{n}-\mathbf{k}-2)\rho_\mathbf{k} \end{aligned} \tag{16}$$

In this study, the corrective factor from [26] was used because the tests carried out by [27] on the power of these methods, show that the modification proposed by Hamed and Rao is slightly better under the AR (1) hypothesis than the formula of Yue and Wang. Indeed, it takes into account the autocorrelation of the regression residuals calculated at the different ranks if they are significant.

3.2.3. Mann-Kendall's Seasonal Test

This test is another variation of Mann-Kendall's classic test used for estimating trends in cyclical or seasonal series.

The principle is based on the classification of data relative to each other according to their rank in the series. However, in the case of Mann-Kendall's test with seasonality, the seasonality of the series is taken into account [28] In other words, for monthly data with a seasonality of 12 months, we will not seek to know if there is an overall growth over the series, but simply if from one month of January to another, from one month from February to the next, and so on, there is a trend.

According to [29], Mann-Kendall's seasonal statistics, Ŝ, for the whole series is calculated according to:

$$\hat{S} = \sum_{\mathbf{g}=1}^{\mathbf{m}} \mathbf{a_{ij}} \tag{17}$$

For this test, the set of Kendall's t (Tau) for each season is calculated first, allowing the calculation of the average Kendall's **t** for the series. The variance of the statistics can be calculated by assuming that the series are independent (for example the values for the months of January and the months of February are independent) or dependent, which requires the calculation of covariance [28].

For the calculation of the p-value of this test, a normal approximation for the distribution of the mean of Kendall's **t** is generally used.

3.2.4. Break Detection Test: Alexanderson's Method or Standard Normal Homogeneity Test (SNHT)

Alexanderson's method or more commonly known as SNHT (normal standard homogeneity test) was developed to homogenize total annual precipitation series [30] or annual mean temperatures [31]. Its performance deteriorates when the change points are close in time or the number of change points increases. One or more neighboring homogeneous and complete series are used to create a series of differences:

$$\mathbf{Q_i} = \mathbf{Y_i} - \frac{\sum_{\mathbf{j}=1}^{\mathbf{k}} \rho_{\mathbf{j}}^2 \mathbf{x_{ij}} \overline{\mathbf{y}} / \overline{\mathbf{x}}}{\sum_{\mathbf{j}=1}^{\mathbf{k}} \rho_{\mathbf{j}}^2} \tag{18}$$

$$1 \le \mathbf{i} \le \mathbf{n} \text{ et } 1 \le \mathbf{j} \le \mathbf{k}.$$

The value of year i of the base series is represented by Y_i while X_{ji} denotes the observation i from the reference series j [32]. The correlation coefficient between the base series and the reference series j is denoted by ρ_j . Under the null hypothesis, the standardized ratios, Z_i, are distributed normally with zero mean and standard deviation of 1. The counter-hypothesis is that there is a change in mean from a certain point, noted by **a**, in the basic series.

$$\mathbf{H}_0 : \mathbf{Z_i} \sim \mathbf{N}(0,1) \ \ \mathbf{i} \in \{1,\ldots\ldots\ldots\ldots,\mathbf{n}\} \tag{19}$$

$$\mathbf{H}_1 : \begin{cases} \mathbf{Z_i} \sim \mathbf{N}(\mu_1,1) & \mathbf{i} \in \{1,\ldots\ldots\ldots\ldots,\alpha\} \\ \mathbf{Z_i} \sim \mathbf{N}(\mu_2,1) & \mathbf{i} \in \{\alpha+1,\ldots\ldots\ldots\ldots,\mathbf{n}\} \end{cases} \tag{20}$$

To find a replacement for this change point, a series of weighted averages is created:

$$\mathbf{T}_\alpha = \alpha \overline{\mathbf{Z}}_1^2 + (\mathbf{n}-\alpha)\overline{\mathbf{Z}}_2^2, \ \alpha = 1,\ldots,\mathbf{n}-1 \tag{21}$$

where $\overline{\mathbf{Z}}_1$ and $\overline{\mathbf{Z}}_2$ are the means of the standardized ratios before and after the jump respectively and n denotes the total number of years in the series. The maximum of the series is extracted and the corresponding α value is the most probable year for a change in mean [32]. If the statistics $\mathbf{T}_\alpha^{\mathbf{max}}$ds its critical value then there appears to be a jump in mean at time a. The amplitude of this jump is estimated by the ratio of the average ratios before and after the jump $\overline{\mathbf{q}}_1 / \overline{\mathbf{q}}_2$. The series is corrected by multiplying the first segment by this ratio. In principle, the mathematics of the two tests (jumps and trends) are applicable to a discontinuity per series. In practice, the test is applied successively until all the segments of the series are considered homogeneous. The critical values for this test were determined by simulating long series of random numbers normally distributed because the exact law of is $\mathbf{T}_\alpha^{\mathbf{max}}$wn.

4. Results and Discussion

Interannual variability was studied using the Hanning low-step filter over the reference period 1980-2016. While trends and breaks in the annual and seasonal streamflow series of the eight hydrometric stations were studied using the seasonal Mann-Kendall test, the Hamed (modified Mann-Kendall) test and the TSNH over the 1980-2016 reference period.

4.1. Seasonal Analysis

Figure 3 & Figure 4 present the results of the trends in seasonal incremental changes from 1980 to 2016.

Note that for the majority of stations over the first half of the year (January to June), the flow time series showed statistically significant increasing trends with a significance interval of 1% to 10%. The stations in the north (Flampleu, Ity and Toulepleu) of the basin always show significant increasing trends regardless of the month of the semester (Figure 3). However, during the second half of the year, the stations are affected by statistically significant decreasing trends with a threshold ranging from 1% to 10%.

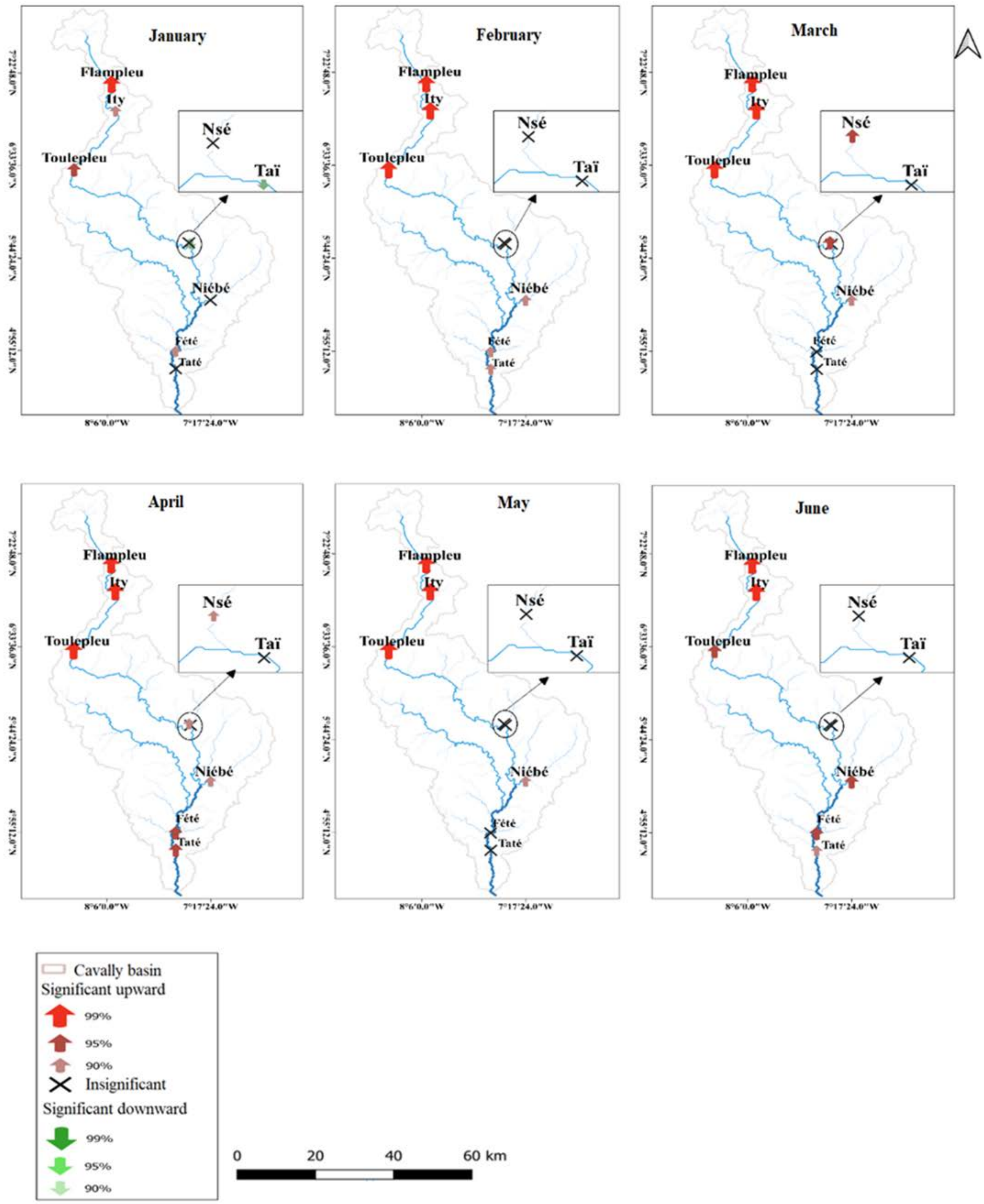

Figure 3. Spatial distribution of Mann-Kendall's seasonal test for the seasonal flow (January to June) of the Cavally watershed from 1980-2016

Some stations often show significant upward trends over this six-month period, specifically the Flampleu station (Figure 4).

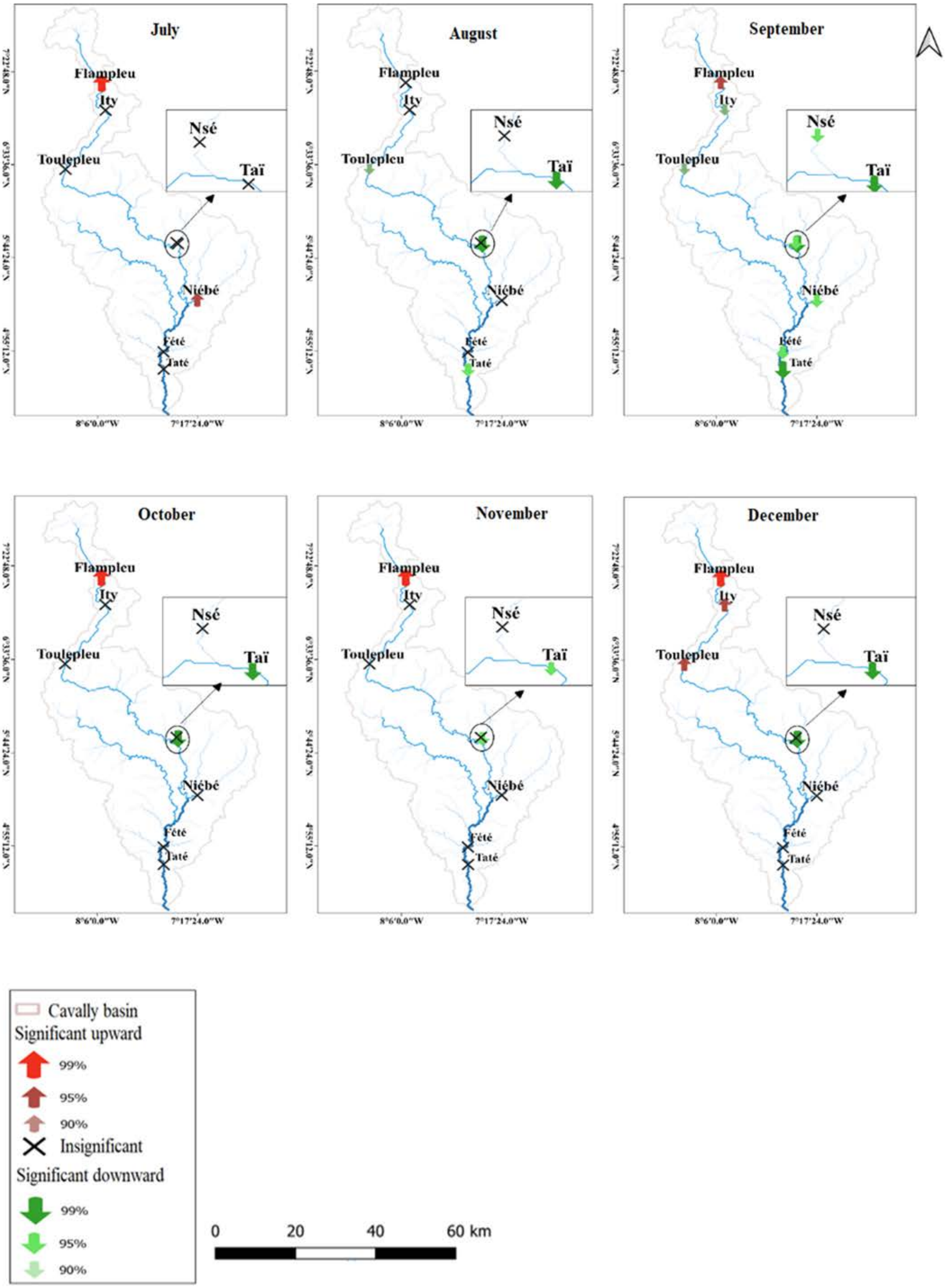

Figure 4. Spatial distribution of Mann-Kendall's seasonal test for the seasonal Flow (July to December) of the Cavally watershed from 1980-2016

4.2. Annual Analysis

4.2.1. Annual Trends and Breaks

The Hamed test performed without taking into account the serial autocorrelation, shows that a significant decreasing (Tai station) and increasing (Flampleu station) trend of the flows at the 1% risk was found (Figure 5A).

The test taking into account the autocorrelation, indicate the same tendencies except that at the level of the station of Taï we observe a fall of the significance of 1% to 5% (Figure 5B).

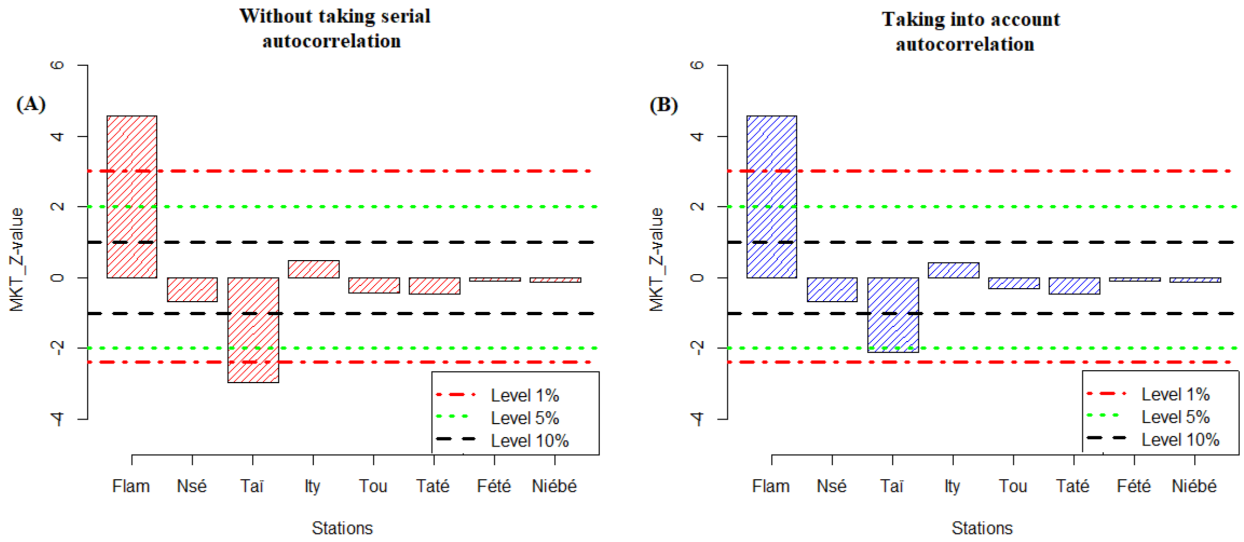

Figure 5. Significance of the statistics of the modified Mann - Kendall test (Hamed, 1998) of the annual flow series of the Cavally watershed (1980-2016)

Figure 6 shows the significance of abrupt changes (breaks) in annual mean flows from 1980 to 2016.

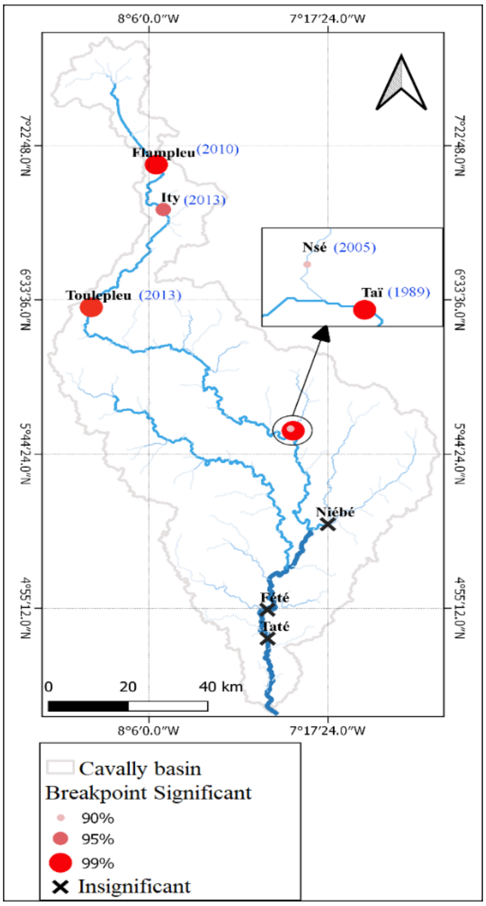

Figure 6. Significance and date of the breaks detected in the annual flow series

On the main river, 62% of the series in the basin are non-stationary and therefore present a significant break. It can be noted that a very large number (80%) of these abrupt changes (breaks) were detected at the 99% risk and are located in the center and north of the basin. While in the south, no significant rupture was detected. The observed breakup dates are generally located between 2000 and 2013 which are late breakups. Nevertheless, only one significant abrupt change was observed since 1989 at the Tai station (α level = 0.05).

Table 1 shows the trends after each detected break. Stations in the northern part of the basin experienced an increase in flow after the year of disruption. Those in the central part of the basin, Tan disc, experienced a decrease. Note that those in the south had no significant change.

Table 1. Years of failure on average annual flows

Stations	TSNH	
	Break years	Period after break point
Flampleu	2010	Upward
Taï	1989	Downward
Nsé	2005	Downward
Ity	2013	Upward
Toulepleu	2013	Upward

4.2.2. Annual Index Analysis

HANNING's 2nd order low pass filter applied to the hydrological series (Figure 7) show a significant interannual irregularity of the flows on all the stations.

At Toulepleu, we observe a long period of deficit from 1980 to 2010 corresponding to a dry period marked by a strong decrease of the flows also recorded by the upstream stations (Ity and Flampleu).

On this period, we can note the presence of some wet years. A surplus period follows the previous one announcing a return of humidity at the end of the observation period 2011 to 2016.

The station of N'cé presents a very long wet period from 1980 to 2005 corresponding to a period marked by an abundance of runoff. This is also affected by years of reduced flow. Finally, a deficit period from 2006 to 2016 (with two wet years) at the end of the observation period describing a dry season. As for the Taï station, it is marked by the alternation of two periods: a wet one at the beginning of the observation period (1980 to 1989) and a very long deficit period from 1990 to 2016. The Niébé station is marked by the beginning of a normal period (1980 to 1988) followed by a very long deficit period from 1989 to 2009 and the beginning of a wet period at the end of the observation period (2010 to 2016). As for the stations of Fété and Taté, they are marked by a dry period from 1980 to 1993 at the beginning of the observation period followed by a long normal period from 1994 to 2003. Finally a normal period from 2004 to 2016.

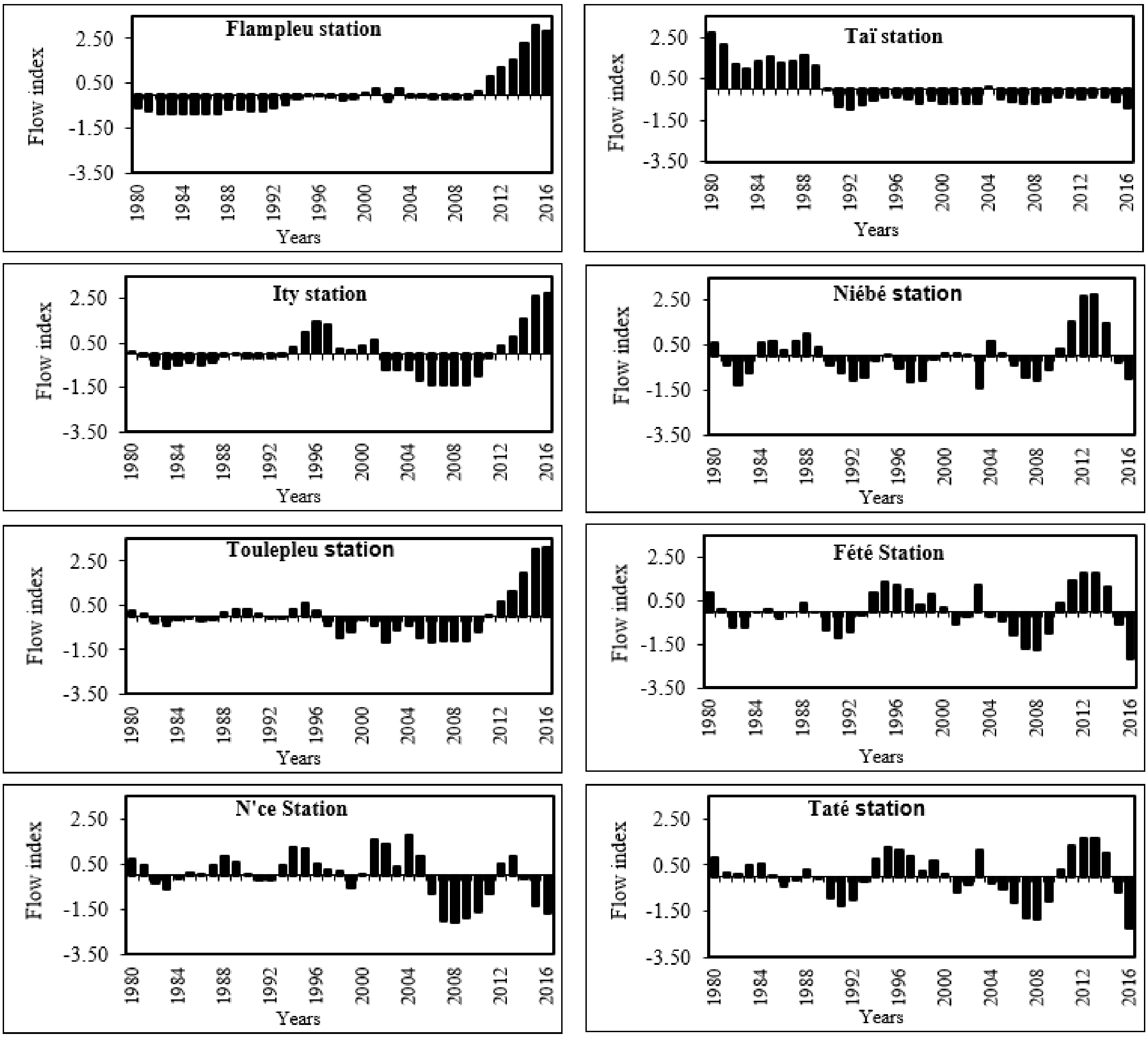

Figure 7. Interannual variability of flow in the watershed of the Cavally River (1980-2016) (1980-2016)

4.3. Discussion

The analysis of the series of mean annual flows allowed us to characterize the hydrometric variability in the Cavally watershed.

- **Interannual variability and rupture**

Statistical methods (break tests, and Hanning low-pass filter of order 2) performed on the time series of annual mean flows in the transboundary Cavally basin show that its variability is marked by alternating climatic periods (two in general).

The northern stations (Flampleu, Ity and Toulepleu) of the Cavally watershed experienced an increase in flow during the transition (deficit to surplus period). This transition is reflected by the presence of break in the flows in the north of the basin and was identified in 2010, 2013 and 2013 respectively in Flampleu, ity and Toulepleu with a significance level of 1% to 5%. The transition (surplus to deficit period) experienced by the stations in the center, shows a decrease in flows that follows the significant breaks (2005 in N'Cé and 1989 in Taï) detected respectively at the threshold of 10% and 1%. The fluctuation of flows can be linked to periods of deficit and surplus rainfall on the one hand and surface conditions on the other hand. Indeed, a decrease in rainfall and/or a high vegetation cover could lead to a reduction in flows [33,34].

The stations in the northern part of the basin experienced an increase in runoff towards the end of the observation period. This may be due on the one hand to a strong modification of the surface condition with a strong regression of the forest in favor of agriculture [34,35,36]. And on the other hand, to the exercise of mining activity. Indeed, some researchers in Africa and around the world [37-42] assert in their work that intense gold mining activities and their consequences (soil embrittlement, progressive destruction of arable land, destabilization of riverbanks and predisposition of soils to often intense erosion processes) affect the morphology, section, and roughness of rivers. This increase could suggest that this region has entered a new climatic phase for some time

[43]. The work of [17] on the Senegal River at Bakel leads to the same result. Indeed, according to these authors, the increase in flow from 1994 to 2004 would mean that this basin has entered a new climatic phase for about ten years.

In parallel to this situation, the central stations (Cavally in Taï and N'Cé in Taï-pont) have experienced a decrease in their runoff after the years of disruption. This decrease may be due to a period of rainfall deficit experienced by this climatic zone and mainly to its high vegetation cover. Indeed, according to [44], the transformation of rainfall into groundwater and streams is reduced because of their interception by forests and their evaporation from the forest cover very high. It is further reduced by the transpiration of soil moisture from the foliage

As for the southern stations, the interannual evolution of runoff is almost normal. This results in an absence of break or in the detection of non-significant break in the increase of the flows. These results obtained deviate from the general logic that admits that the hydrometric ruptures occur following the pluviometric ruptures. Indeed, the length of the hydrometric series studied (1980-2016) could be the reason for this result [13,35,36,45].

• **Trends**

The seasonal Mann-Kendall trend test applied to the seasonal flows of the Cavally basin during the period 1980-2016, highlights two trend periods.

A period from January to June corresponding to the low water season in the basin. Over this period, the flow time series showed statistically significant increasing trends with a significance interval of 1% to 10%. It should be noted that during this period, the stations in the north of the basin, i.e. those located in the mountain regime, always showed statistically significant increasing trends. The second period runs from July to December and corresponds to the average and high-water season in the basin. During these months, the majority of the stations are affected by statistically significant decreasing trends with a threshold ranging from 1% to 10%. The trends detected, significant or not, indicate an increase (January to June) and a decrease (July to December) in monthly runoff during the year. According to [33] and [34], the increases can be linked to an increase in rainfall and the decreases to a decrease. However, it should be noted that the surface condition has a strong influence on the nature of runoff [36]. Indeed, the increases can be due on the one hand to a strong modification of the surface state with a strong regression of the forest in favor of agriculture [34,35,36]. And on the other hand, to the exercise of mining activity and urbanization that generally leads to alterations of natural soil surfaces (decrease in surface permeability and roughness) and the morphology of the courses (high density of drainage, modification of the slope of the watercourses ...) [37-42].

The modified Mann-Kendall trend test applied to the annual runoff of the Cavally basin during the period 1980-2016 shows that 25% of the series present a significant trend without taking into account the autocorrelation with a threshold of 1%. The test performed taking into account the autocorrelation still shows that 25% of the stations present a significant trend with a decrease in significance (from 1 to 5%) at the station of Taï. The general trend of the annual runoff of the basin is decreasing with a majority of 75% of non-significant. This high rate of non-significance may be related to the method used [28,46,47]. Indeed, according to its authors, the method used contains limitations related to the power of statistical tests because a non-significant trend may not prove the absence of a trend, but simply illustrate the inability of the test to detect it. Thus, caution must be exercised in interpreting the physical significance (or lack thereof) of the absence of statistically significant trends in runoff [48], as these and other stations do experience declining trends in runoff volumes with climate variability and pejoration. Thus, further, more in-depth research is needed to establish the primary reasons for these two contrasting results.

5. Conclusion

In the present study, the analysis of trends and evolution of spatio-temporal variability in flow time series was carried out in the Cavally transboundary basin. For this fact, MK's tests (original, modified and seasonal); SNHT, and Harnning filter were applied to each time series. From the results obtained in the study, the following conclusions can be drawn: (1) Stations in the northern part of the basin generally experienced a long dry period from 1980 to 2010 and a wet period 2011 to 2016 and those in the central part, a wet period from 1980 to 2005 and dry from 2006 to 2016. stations in the central part are marked by an alternation of normal periods. (2) The significant increase in runoff during the dry season and some months of the rainy season was the main reason for the increase in annual runoff due to the considerable contributions of these seasons to the total volume of flow in the Cavally basin. (3) Based on the results of the SNHT test for detecting abrupt changes in the series, about 62% of the series show a significant break, 60% of which are upward at the 5% to 1% significance level. All observed breaks are generally located between 2000 and 2013.

Overall, the results obtained in this study can provide a scientific reference for sustainable water resources management in West Africa.

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