

Original Research Article

Recent rainfall trend and abrupt changes over Cavally basin (West Africa)

Abstract

Aims: Analyze the recent variations in annual and monthly precipitation at 18 pluviometry stations in the Cavally river basin

Place and Duration of Study: Data of month and annual rainfall data of 37 years (1980-2016) collected from the National direction of Meteorology for Ivory Coast and Guinea and from <https://app.climateengine.org/climateEngine> for Liberia.

Methodology: Statistical methods are used to highlight the evolution of cumulative annual rainfall and the distribution of the different seasons over the period 1980-2016. Hanning's low pass, Mann-Kendall classic test, modified Mann-Kendall test, Mann-Kendall seasonal test and Standard Normal Homogeneity Test were applied to identify the existing trend direction and significance of change over time.

Results: The periods 1980-1996 and 1997-2016 could be considered as wet and dry periods respectively (with a rainfall deficit of 18% after the break in 1996). In addition, we observe a decrease in rainy days of strong accumulation that lead to a significant drop in total annual rainfall. Finally, an abnormal increase in rainfall during the dry season months and a decrease in rainfall during the rainy season months. This indicates an intra-seasonal irregularity (shortening of the rainy season and prolongation of the dry season) of precipitation.

Conclusion: The Hanning filter, M-K test and SNHT are non-parametric tests widely used in the study of climate trends. However, the additional consideration of serial autocorrelation (MM-K test) and seasonal trends (M-K-S test) allows to extend and refine the information on climate variability.

Key words: Autocorrelation in trend significant, Cavally basin, recent rainfall evolution, spatio-temporal seasonal trend, statistical methods.

1. Introduction

Global warming accelerates the process of evapotranspiration that further modifies the precipitation regime due to the increased capacity of the atmosphere to retain moisture according to the Clausius-Clapeyron relationship [1]. The rainfall regime is the main factor of productivity in developing countries. It conditions the availability of water and agricultural products in Africa [2]. However, for decades, all the countries of West Africa have experienced high climatic variability [3 - 6]. This is manifested by

a change in the rainfall regime and by a decrease in annual rainfall levels [6 - 8]. The harmful effects of this climatic variability (rainfall irregularity, uncertainties about extreme events and temperature rise) influence the performance of dependent activities (hydroelectric, agricultural dams, hydrological balance and access to drinking water for human consumption) of this [9 - 11].

Then, according to [12] and [13], after the very long (1968-1995), very extensive (more than 6 million km² very affected) and very pronounced (from 10 to 40% decrease in precipitation depending on the location) dry episode experienced in West Africa, we are witnessing an undeniable resumption of rainfall in this area. In Côte d'Ivoire, recent studies [14, 15] have shown an increase in rainfall in the north and south of the country from 2000 and 2003 respectively. However, very little information is available about increase in rainfall in Cavally watershed. This situation is linked to the fact that the transboundary watershed of the Cavally River located west and south-west of Côte d'Ivoire, east of Liberia and north-east of Guinea is very little studied. However, the analysis of the manifestations of climate variability is a development issue because it should lead to the development of scenarios allowing the forecasting and sustainable management of water resources [16]. The main objective of this study is therefore to provide a holistic analysis of recent rainfall trends observed in the Cavally river basin. Specifically, this study aims to (i) identify the new distribution of the rainy seasons in the basin (ii) examine the trends and abrupt changes in annual and monthly rainfall amounts.

2. Material

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%).

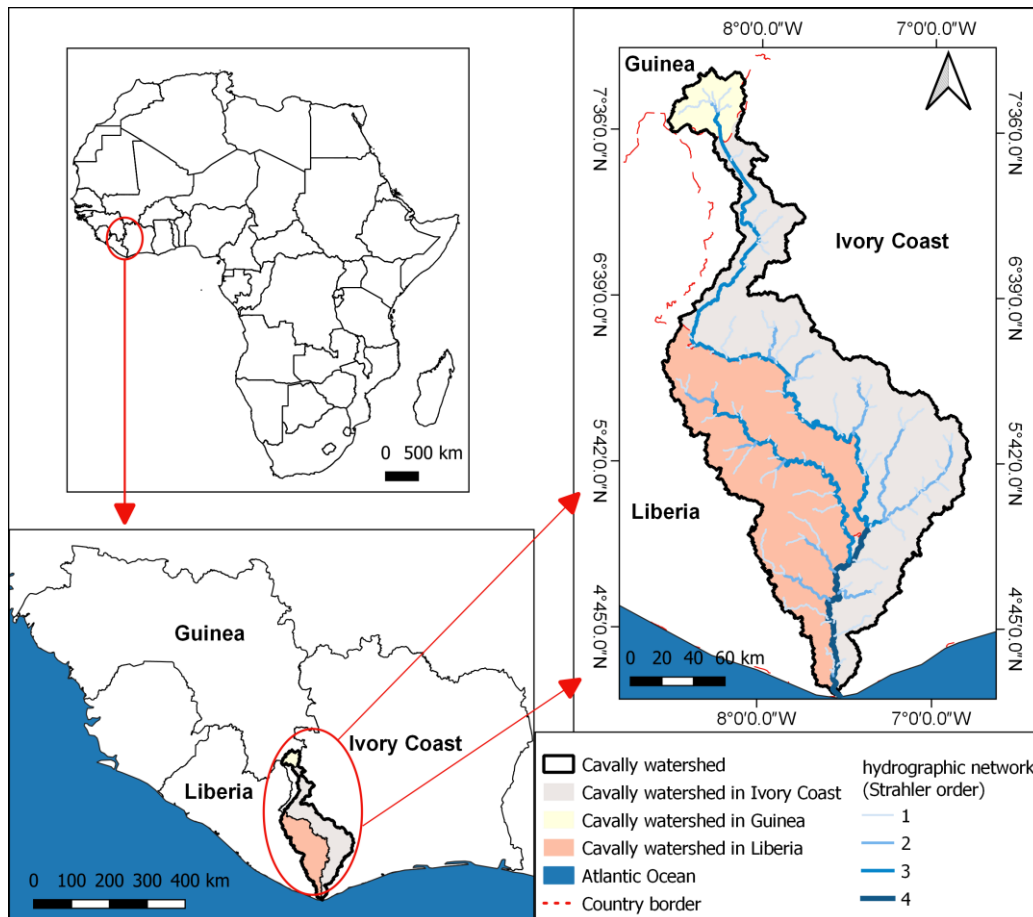


Figure 1: Geographical location of the Cavally river basin

2.2. Data

The database used is monthly and annual rainfall from eighteen (18) rainfall stations distributed as follows: fifteen (15) in Côte d'Ivoire, two (2) in Liberia, and one (1) in Guinea. The data for the Ivory Coast was provided by the National Direction of Meteorology (SODEXAM). In Guinea, rainfall data was provided by the National Direction of Meteorology (DNM). In Liberia, the lack of rainfall data because of the civil war in the 80s and 90s, we have used the satellite data (<https://app.climateengine.org/climateEngine>). The rainfall data used in this study covers the period 1980-2016. Figure 2 shows the spatial distribution of the rainfall stations used in this study.

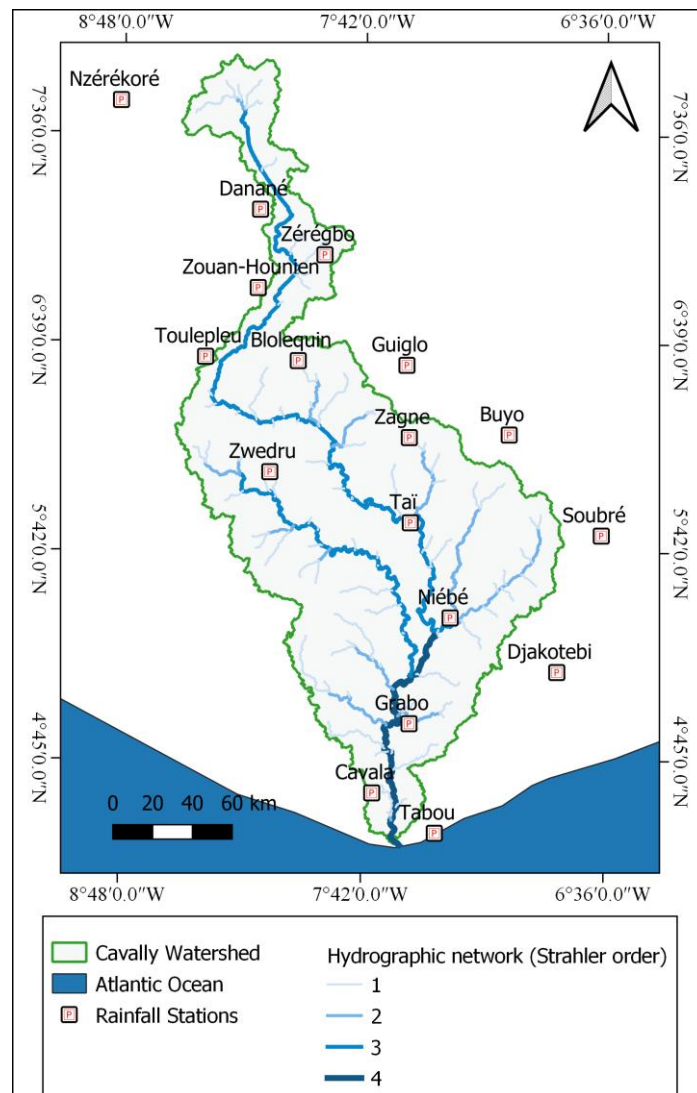


Figure 2: Geographical location of the rainfall stations in Cavally watershed

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 [17]. In particular, Mann-Kendall's test [18, 19] which is generally used to detect trends in climate data becomes highly biased in the presence of autocorrelation [17]. 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 [20]. According to this method, each term in the series is calculated by equation 4:

$$X_t = 0.06x_{t-2} + 0.25x_{t-1} + 0.38x_t + 0.25x_{t+1} + 0.06x_{t+2} \quad (1)$$

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) :

$$X_1 = 0.54x_1 + 0.46x_2 \quad (2)$$

$$X_2 = 0.25x_1 + 0.50x_2 + 0.25x_3 \quad (3)$$

$$X_{n-1} = 0.25x_{n-2} + 0.50x_{n-1} + 0.25x_n \quad (4)$$

$$X_n = 0.54x_n + 0.46x_{n-1} \quad (5)$$

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 ...:

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

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 [21]. More particularly, this nonparametric trend test is the result of an improvement of the test first studied by [18] then taken up by [19] and finally perfected by [22].

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

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n a_{ij} \quad (7)$$

Or:

$$(8)$$

$$a_{ij} = \text{sign}(x_j - x_i) = \text{sign}(R_j - R_i) = \begin{cases} 1 & \text{si } x_j > x_i \\ 0 & \text{si } x_j = x_i \\ -1 & \text{si } x_j < x_i \end{cases}$$

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. [19], gives the mean and variance of the above S-test statistics:

$$E(S) = 0 \quad (9)$$

$$\text{Var}(S) = \frac{n(n-1)(2n+5)}{18} \quad (10)$$

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:

$$\text{Var}(S) = \frac{n(n-1)(2n+5)}{18} - \frac{\sum_{j=1}^m t_j(t_j-1)(2t_j+5)}{18} \quad (11)$$

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:

$$Z = \begin{cases} \frac{(S-1)}{\sqrt{V_0(S)}} & \text{si } S > 0 \\ 0 & \text{si } S = 0 \\ \frac{(S+1)}{\sqrt{V_0(S)}} & \text{si } S < 0 \end{cases} \quad (12)$$

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:

$$\text{Var}_\rho(S) = \gamma * \text{Var}_{\rho=0}(S) \quad (13)$$

where γ is a corrective factor applied to the variance.

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

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

$$(14)$$

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

where ρ_1 denotes the autocorrelation of order 1

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

$$\gamma = 1 + \frac{2}{n(n-1)(n-2)\rho_1} \sum_{k=1}^{n-1} (n-k)(n-k-1)(n-k-2)\rho_k \quad (15)$$

In this study, the corrective factor from [24] was used because the tests carried out by [25] 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 [26] 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 [27], Mann-Kendall's seasonal statistics, \hat{S} , for the whole series is calculated according to:

$$\hat{S} = \sum_{g=1}^m a_{ij} \quad (16)$$

For this test, the set of Kendall's t (Tau) for each season is calculated first, allowing the calculation of the average Kendall's τ 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 [26].

For the calculation of the p-value of this test, a normal approximation for the distribution of the mean of Kendall's τ 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 [28]

or annual mean temperatures [29]. 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:

$$Q_i = Y_i - \frac{\sum_{j=1}^k \rho_j^2 x_{ij} \bar{y} / \bar{x}}{\sum_{j=1}^k \rho_j^2} \quad (17)$$

$$1 \leq i \leq n \text{ et } 1 \leq j \leq k \quad (18)$$

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 [30]. 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 α , in the basic series.

$$H_0: Z_i \sim N(0, 1) \quad i \in \{1, \dots, n\} \quad (19)$$

$$H_1: \begin{cases} Z_i \sim N(\mu_1, 1) & i \in \{1, \dots, \alpha\} \\ Z_i \sim N(\mu_2, 1) & i \in \{\alpha + 1, \dots, n\} \end{cases} \quad (20)$$

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

$$T_\alpha = \alpha \bar{Z}_1^2 + (n - \alpha) \bar{Z}_2^2, \quad \alpha = 1, \dots, n - 1 \quad (21)$$

where \bar{Z}_1 and \bar{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 [30]. If the statistics T_α^{max} exceeds its critical value then there appears to be a jump in mean at time α . The amplitude of this jump is estimated by the ratio of the average ratios before and after the jump \bar{q}_1 / \bar{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 T_α^{max} unknown.

4. Results and discussion

4.1. Seasonal analysis

Figure 3 shows the monthly rainfall trends for the first semester (January to June). Overall, very few significant trends were detected in the monthly rainfall series (12%

in January, 41% in February, 12% in March, 5% in April and 35% in June). These trends indicate an increase in monthly rainfall at all affected stations except at the Tai (in March) and Danané (in June) stations, where there is a decrease at the 5% risk, *i.e.*, a significance level of 95%. The monthly trends detected in the second half of the year (July to December) are presented in Figure 4. Significant decreases were observed in the first four months of the second semester (July to October). The downward significance was observed over the first four months of the semester (July to October) with a high number of stations affected (88%) in the months of August and September. While those on the rise, are observed over the last two months (November and December) of the semester. In November, 53% of resorts are affected by this trend and 23% in December.

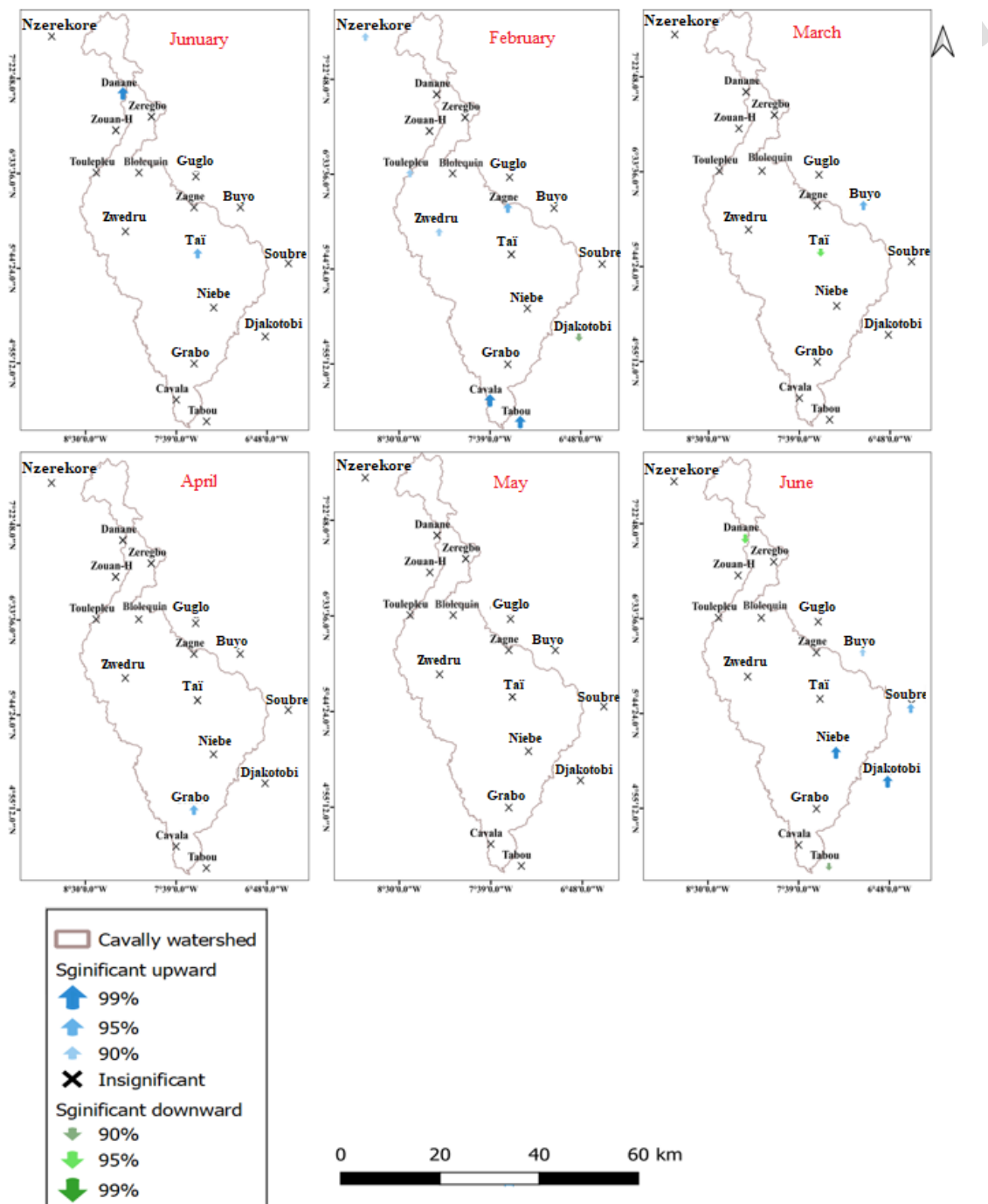


Figure 3: Spatial distribution of Mann-Kendall's test for the seasonal precipitation of the Cavally watershed from 1980-2016

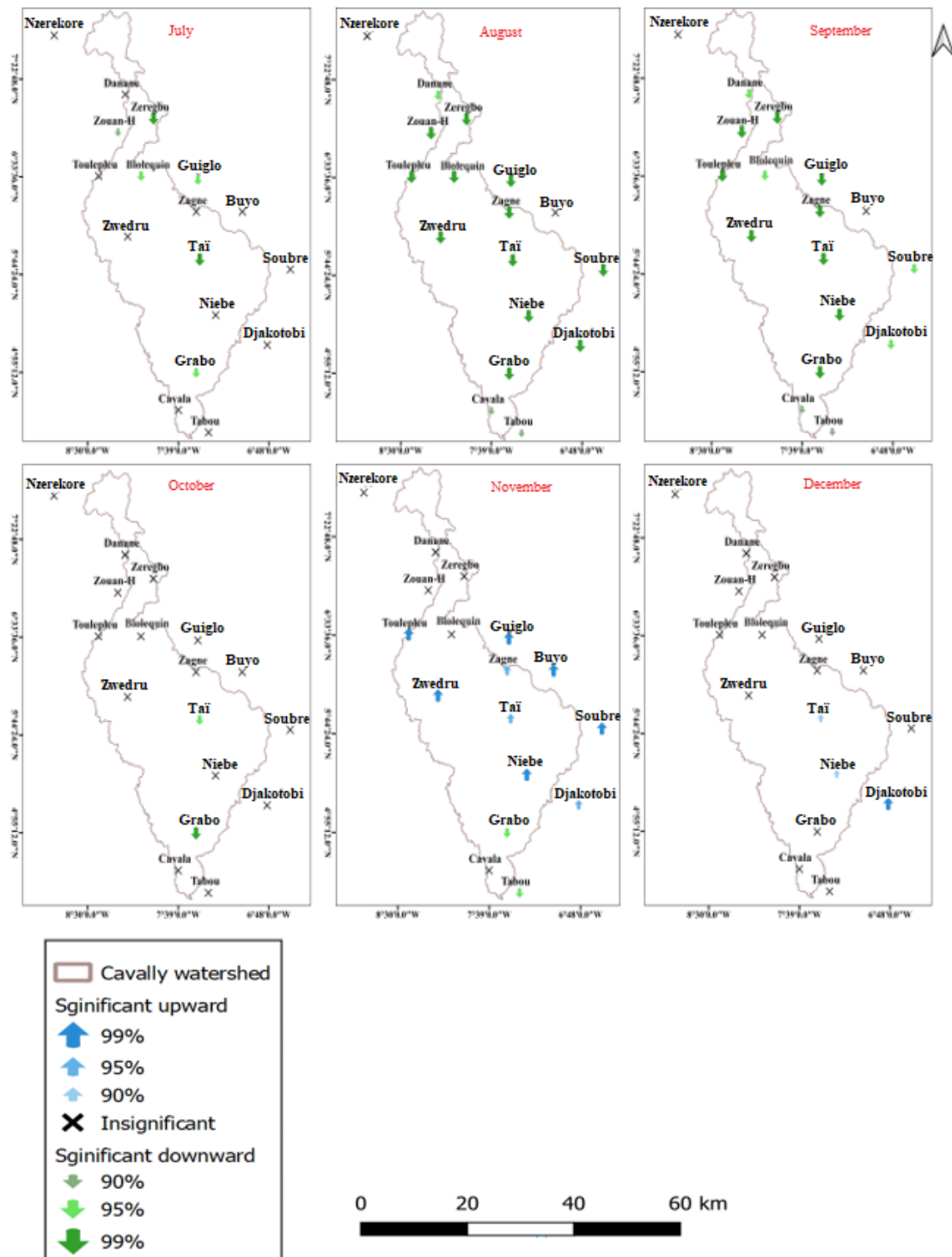


Figure 4: Spatial distribution of Mann-Kendall's test for the seasonal precipitation of the Cavally watershed from 1980-2016.

4.2. Annual Analysis

4.2.1 Annual trends and breaks

The results of the Mann-Kendall test with and without taking into account the serial autocorrelation are presented in figure 5. Mann-Kendall's test, carried out without taking serial autocorrelation into account, shows that only 11% of the stations (Djakotobi and Nzérékoré) show a significant upward trend (risk of 10%). Moreover, 65% of stations are affected by a downward trend at risk of 1%, 5% and 10%. As for the one taking into account autocorrelation, we still note that 11% of stations show a significant upward trend. Nevertheless, this time with an increase in significance (from 10% to 1%) at the Djakotobi station. 71% of stations are affected by a downward trend. Among them, some have seen their significance decrease (Boulequin, Zwédru, Zagne and Toulepleu) and others. On the other hand, their significance increase (Tabou and Cavala) (figure 5).

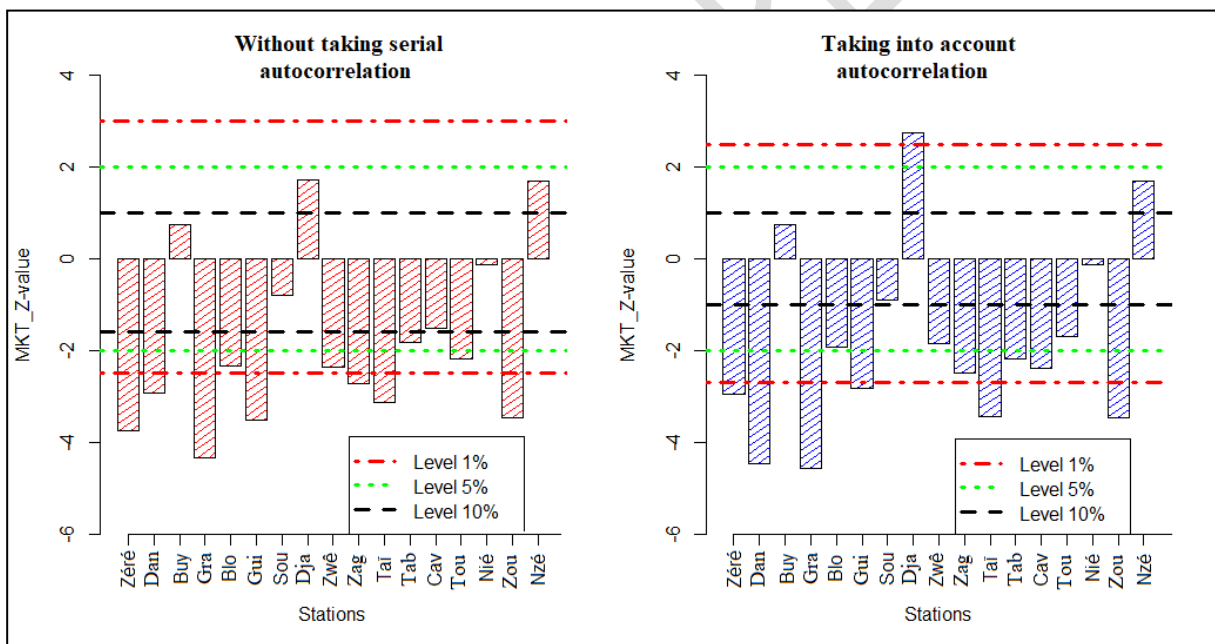


Figure 5: Significance of the statistics of the modified Mann - Kendall test (Hamed, 1998) of the annual rainfall series of the Cavally watershed (1980-2016)

The application of the break detection test (SNHT) made it possible to identify significant breaks (sudden changes) in the annual rainfall series (Figure 8) and the rainfall evolution after these years of breaks (Table I). The null hypothesis of no rupture was rejected at the 99%, 95% and 90% confidence levels at all stations, except those of N'Zérékoré, Niébé, Djakotobi and Soubré.

Figure 6 shows that 82% of the annual rainfall series in the basin are non-stationary and therefore show a significant break. It can be noted that a very large number of these abrupt changes (rupture) were detected at 99% risk and are located in the north-central part of the basin. While in the south, are based the significant ruptures at risk of 90% all detected in 2012.

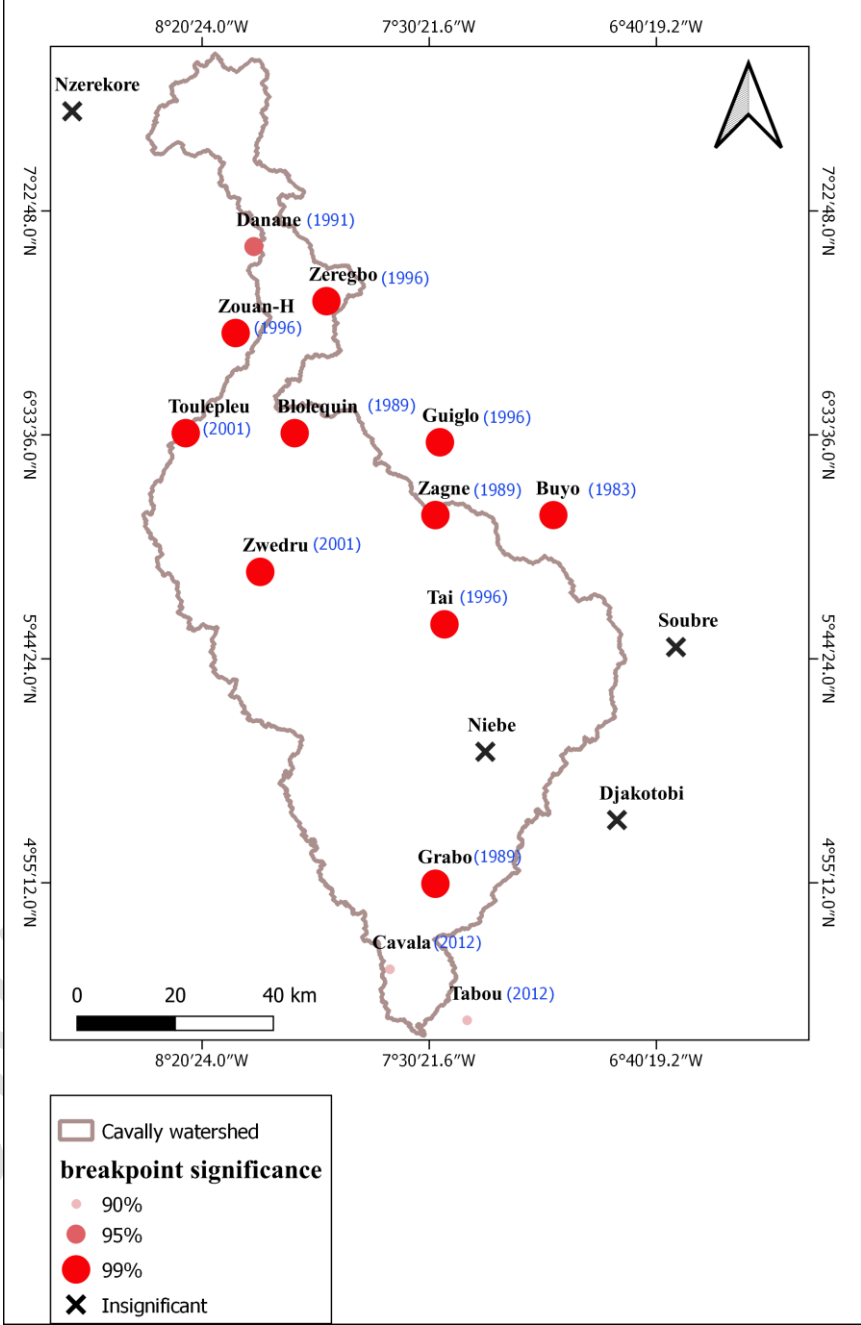


Figure 6: Significance and date of the breaks detected in the annual rainfall series

Table I shows the trends after each break detected. All the stations in the basin experienced a drop in rainfall after the year of rupture.

Table I : Years of failure on average annual flows

Station	TSNH		Deficit (%)
	Break years	Period after break point	
Danané	1991	downward	-25
Zérégbo	1996	downward	-45
Zouan_Hounien	1996	downward	-36
Toulepleu	2001	downward	-23
Bolequin	1989	downward	-31
Guiglo	1996	downward	-29
Zagne	1989	downward	-30
Buyo	1983	upward	52
Zwedru	2001	downward	-22
Taï	1996	downward	-32
Grabo	1989	downward	-34
Cavala	2012	downward	-35
Tabou	2012	downward	-45

4.2.2. Annual rainfall index analysis

The interannual change in rainfall in the Cavally River basin is presented in Figures 7 and 8. The analysis of this trend shows that the entire basin is marked by an alternation of period of wet and dry of rainfall. About 76% (13 out of 17) of the stations were affected by two climatic periods, which marked their rainfall variability. The stations each experienced a period of excess rainfall generally ranging from 1980 to 1996 and a long period of deficit rainfall (generally from 1996 to 2016). However, stations in N'Zérékoré and Djakotobi had a surplus period from 1993 to 2016 and a deficit period from 1980 to 1994. Thus, that of Buyo which is (1985 à 2013).

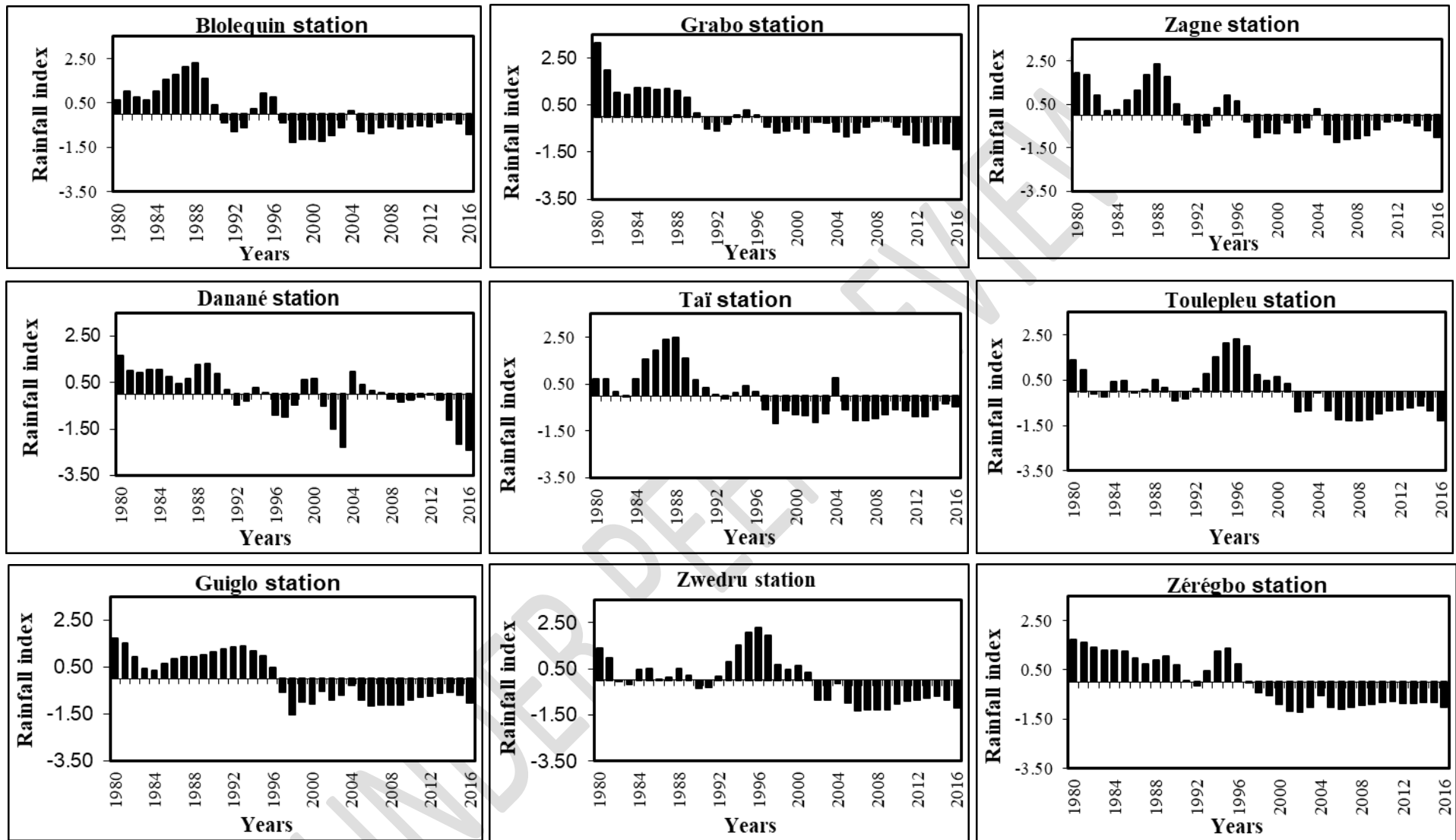


Figure 7: Interannual variability of rainfall with two climates periods in the watershed of the Cavally River (1980-2016)

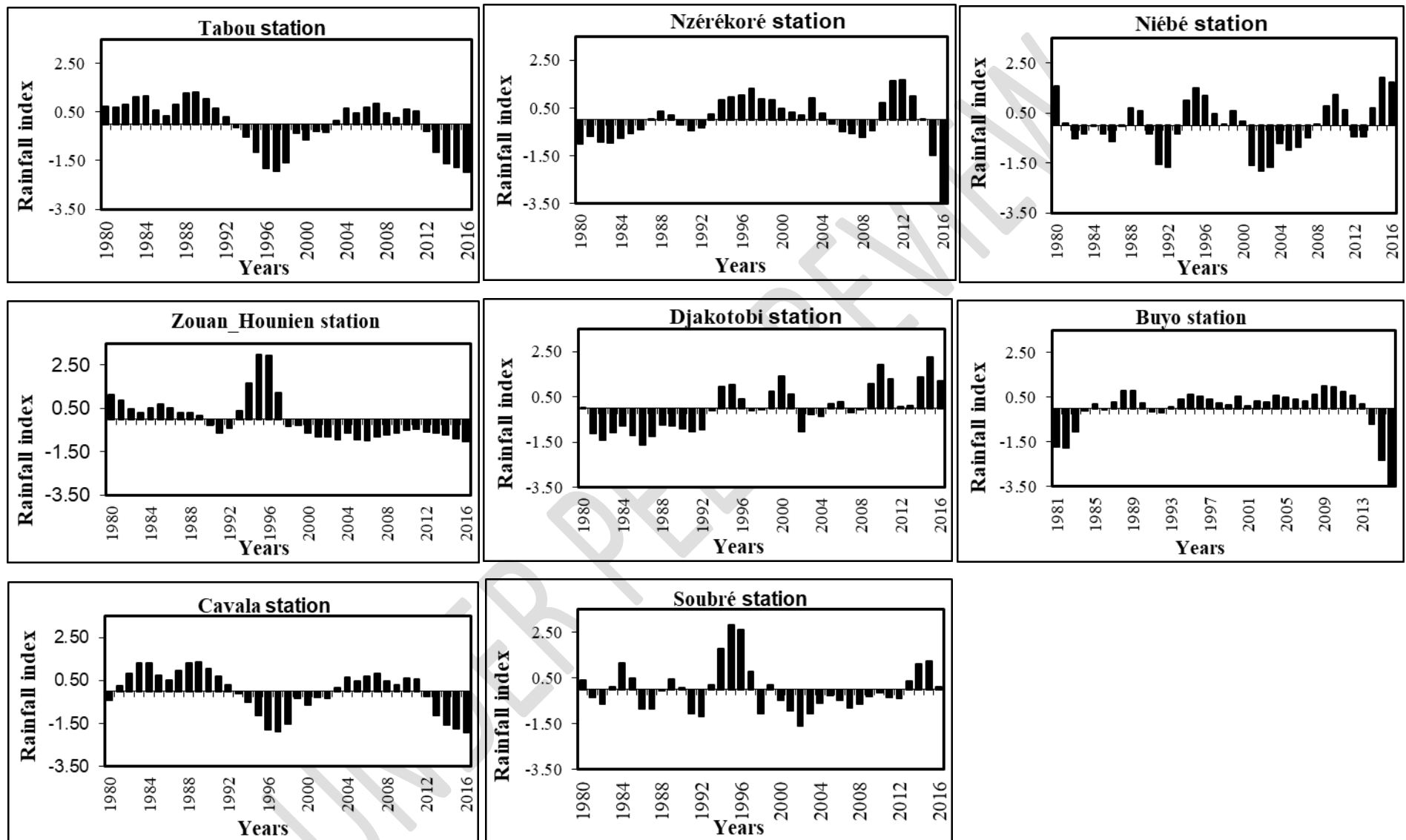


Figure 8 : Interannual variability of rainfall in the watershed of the Cavally River (1980-2016)

4.3. Discussion

The analysis of rainfall series made it possible to characterize climate variability in the Cavally watershed.

➤ Trends

The seasonal Mann-Kendall trend test applied to the seasonal precipitation of the Cavally basin during the period 1980-2016, shows two seasons.

A season going from November to March corresponding to the great dry season of the basin. During these months very few significant trends per month (53% in November 23% in December 12% in January, 41% in February, 12% in March, 5% in April and 35% in June). These detected trends, significant or not, indicate an increase in monthly rainfall, that is to say an increase in the number of rainy days during certain months this season. Klassou and Komi, 2021 found that the drought index showed increasing trends in much of their study area (Oti river basin).

The second season with two rainy episodes corresponding to the great rainy season (April to October). The first episode (April to June) during which the series very often show decreasing trends but not significant. As for the rest of the months of this season (second episode), 60-80% of the series are affected by a significant decrease in rainfall with a risk of significance ranging from 1% to 10%. These results indicate that during the study period, during the rainy season (both episodes), precipitation in the Cavally watershed experienced a decrease in its monthly contribution precisely the number of rainy days. These decreases in heavy rainfall events have been observed in the northern ZITC and the central tropics [31]. In addition, in relation to our results concerning heavy rains, the study by [11] predicted a downward trend in heavy precipitation indices in the worst-case scenario of climate change (RCP8.5). of the International Panel on Climate Change in the Ouémé Basin in the Republic of Benin (West Africa), while [32] demonstrated a significant increase in intensity of heavy rainfall by 2050 in the Mono river basin (Togo and Benin).

The abnormal increase in the number of rainy days during the dry season and the decrease in the number of rainy days during the rainy season indicate an intra-seasonal irregularity in precipitation. This may be due to a change in the start and end date of the rainy season in the Cavally basin. The work of [10]; [11]; [33], [31]; [34], and [35], confirmed this irregularity. According to them, the dates of the start of the rainy season have become much earlier again, and the end dates have changed less. Specifically, [1] found a general reduction in the indices of extreme precipitation (except periods of drought) and a very slight downward trend in the occurrence of heavy precipitation from higher return periods, to namely 25, 50, 75 and 100 years were found in their works.

Likewise, in Central Africa and Guinea Conakry, the conclusions of [36] agree with our results. Indeed, these authors indicate downward trends in heavy precipitation indices.

The modified Mann-Kendall trend test applied to the annual precipitation of the Cavally basin during the period 1980-2016 shows that 76% of the series show a significant trend without taking into account the autocorrelation with a threshold ranging from 1% to 10%. As for the one carried out taking into account the autocorrelation, we note that 82% of the stations show a significant trend. However, this time with an increase in significance (from 10% to 1%) at the Djakotobi station. Among them, some have seen the statistic (Z) of the test of their series vary, that is to say their significance decreases (Blequin, Zwêdru, Zagne and Toulepleu) and increases for others (Tabou and Cavala) (figure 7). Indeed, these results show that the presence of autocorrelation in the series biases the significance of the tests and therefore can lead to aberrant or apparent trends. This conclusion is in agreement with the studies of [37] on the evolution of the maximum annual intensities of hourly rains in Côte d'Ivoire. They point out that whether the trend is significant or not, the presence of a positive autocorrelation structure in a series of rainfall data seems to significantly disrupt the statistical tests by introducing apparent trends. [21] agrees and points out that the presence of a positive autocorrelation in the series increases the probability to have a significant response, even in the absence of a trend. The apparent trends are often due to the slow decay of the autocorrelation function. In the case of strongly autocorrelated series, the apparent trends rarely result from long-term deterministic change. Some authors [23, 38] indicate that the presence of autocorrelation causes a high rate of rejection of the stationarity hypothesis (absence of trend). In contrast, [39] point out that the presence of a negative autocorrelation induces the opposite effect.

All the significant trends detected on the self-correlated or non-self-correlated series are mainly (60% to 70%) downward and a minority (11%) upward. This means that the annual rainfall of stations in the basin has decreased significantly although it has increased at some station over the period 1980-2016. These results are in agreement with those found in the work of [40] in Benin. This author claims that similar decreases and increases in annual precipitation totals have also been observed in different parts of the country. [41] also demonstrated that rainfall in West Africa decreased in the second half of the 20th century. Almost all of the studies on climate variability in West Africa [42, 7, 8], particularly in Côte d'Ivoire [43 - 45], confirm the general downward trend in rainfall which would be due to climate change due to global warming which would be a consequence of numerous human activities.

➤ **Interannual variability and rupture**

The statistical methods (SNHT and Hanning low-pass filter of order 2) carried out on the chronological series of annual precipitation over the transboundary Cavally basin show that its variability is marked by two climatic periods.

Hanning low-pass filter of order 2 shows in general that, all-time series show the presence of a wet (generally from 1980 to 1996) and dry (1997 to 2016) periods with decreasing and regular annual quantities, with the exception of those of N'Zérékoré, Buyo and Djakotobi. This decrease was manifested by significant and non-significant breaks (Djakotobi, Niébé, Soubré and N'Zérékoré) within the time series. Indeed, the dates 1983 (Buyo), 1996 (Zérégbo, Zouan-Hounien, Guiglo and Taï), 1989 (Zagne and Bolequin), 1991 (Danané), 2001 (Toulepleu and Zwedru), and 2012 (Cavala and Tabou) are dates of significant ruptures identified by the SNHT test. Then, the rainfall deficits of these different breaks vary between 20% and 45%. It should also be noted that these methods applied to the average annual rainfall (from 1980-2016) of the transboundary watershed of Cavally, shows two climatic periods. A wet ranging from 1980 to 1996 and a dry one from 1997 to 2016 with a deficit of 18%. These two periods are separated by a break in 1996 identified by the SNHT test. In addition, most of the abrupt changes appear in the period of severe drought (1968-1990) and in 1996. The ruptures of 1996 may be a continuation of the drastic drought experienced in West Africa. These results are in agreement with the different points of change that have been detected in several previous studies of rainfall variability in West Africa [46 - 48] and in Côte d'Ivoire [16, 44, 49]. Finally, the breaking points observed in the other years are not associated with any period and could therefore reflect a new reference for recent stationarity studies.

5. Conclusion

The characterization of rainfall trends in the transboundary basin of the Cavally River was studied in this study. The objective was to study the recent evolution of annual and seasonal precipitation in the Cavally basin. MK's tests (original, modified and seasonal); SNHT, IDW, and hanning filter were applied to each time series. The basin has experienced on average two climatic periods, both separated by a break in 1996. The wet period starts from 1980-1996 and the dry period from 1997-2016. Significant decreases for rainfall over time were observed, except for some stations (Djakotobi and Nzérékoré) which experienced a significant increase. The results of the monthly analysis show significant downward trends for July, August and September during the rainy season and a marked increase in some months of the dry season, thus illustrating the impact of these trends on total annual precipitation. The trends detected are not systematically attributable to a climatic signal. The geographical space of rainfall by decade shows a regular drop in rainfall (from 1980-2016) with a recovery during the decade 2000-2009. At the end of this study, the rainfall in the Cavally basin is generally on a downward trend. With the appearance of a probable new year of rupture varying

between 1989 and 1999. This study should be extended to all the basins in Côte d'Ivoire or West Africa to determine the relevance of the new rupture (1996) detected.

References

1. Klassou K, Komi K. Analysis of extreme rainfall in Oti River Basin (West Africa). *Journal of Water and Climate Change*. 2021; doi: 10.2166 / wcc. 2021,154
2. Derving B, Monsia J-CK, Ernest KA, Davilla AAA, Teti PT. Study of the spatial variability of rainfall by the geostatistical and idw (inverse distance weighted) method in the center-west of the Ivory Coast. *American Journal of Innovative Research and Applied Sciences*. 2019; 9 (2): 2016-223. French
3. Paturel JE, Servat E, Kouamé B, Lubès-Niel H, Ouedraogo M, Masson JM. Climatic variability in humid Africa along the Gulf of Guinea. Part two: an integrated regional approach. *Journal of Hydrology*. 1997; flight. 191, 16-36p.
4. Servat E, Paturel JE, Lubès NH, Kouamé B, Masson JM, Travaglio M, Marieu B. Different aspects of rainfall variability in non-Sahelian West and Central Africa. *Journal of Water Sciences*. 1999; 12 (2), pp. 363-387. French
5. Ardoin BS. Hydroclimatic variability and impacts on the water resources of large hydrographic basins in the Sudano-Sahelian zone. Doctoral thesis, University of Montpellier II, France, 225 p. 2004
6. Kouassi AM, Kouamé KF, Goula BTA, Lasm T, Paturel JE, Biémi J. Influence of climatic variability and modification of land use on the rainfall-runoff relationship from a global modeling of the basin side of N'zi (Bandama) in Ivory Coast. *Science and technology*. 2008; 11: 207-229. French
7. Sylla MB, Nikiema PM, Gibba P, Kebe I, Klutse NAB. *Climate change over West Africa: recent trends and future projections*. Springer, New York. 2016; <https://doi.org/10.1007/978-3-319-31499-03>

8. Ilori OW, Ajayi VO. Change Detection and Trend Analysis of Future Temperature and Rainfall over West Africa. *Earth Syst Environ.* 2020; 4: 493–512.
9. Doumbia S, Depieue ME. Peasant perception of climate change and adaptation strategies in rainfed rice cultivation. *Journal of Applied Biosciences.* 2013; 64: 4822-4831.
10. DESCROIX L, Aïda DN, Gérémy P, Ansoumana B, Youssouph S, Honoré D, Moussa MA, Jean-Pierre V, Guillaume Q. Recent trends in rainfall in West Africa across two regions: Senegambia and the Middle Niger Basin, *Climatology.* 2015 ; p. 25-43
11. M'Po NY, Lawin, AE, Yao KB, Oyerinde TG, Attogouinon A, Afouda AA. Decreasing past and mid-century rainfall indices over the Ouémé River Basin, Benin (West Africa). *Climate.* 2017; 5, 74. doi: 10.3390 / cli5030074.
12. Descroix L, Diongue-Niang A, Dacosta H, Panthou G, Quantin G, Diedhiou A. Evolution of extreme rains and upsurge in floods in the Sahel. *Climatology.* 2013; 10, 37-49.
13. Bodian A .: Characterization of the recent temporal variability of precipitation annuals in Senegal (West Africa). *Physio-Géo [Online].* 2014 ; Volume 8: 297-312 | 2014, DOI: <http://dx.doi.org/10.4000/physio-geo.4243>.
14. Irié GR, Soro GE, Goula BTA. Changes in surface conditions and spatio-temporal changes in precipitation in the watershed of the Marahoué (Ivory Coast), *International Journal of Innovation and Applied.* 2015.
15. Koné KHC, Coulibaly K, Konan KS. Identification of some plants used in ethnoveterinary medicine in Sinématiali (North of the of Ivory). *Journal of Applied Biosciences.* 2019; 135: 13766 - 13774.
16. Kouassi AM. Characterization of a possible modification of the rainfall-flow relationship and its impacts on water resources in West Africa: case of the N'zi (Bandama) watershed in Côte d'Ivoire. Single Doctorate Thesis, University of Cocody, Ivory Coast, 210 p. 2007

17. Biteye M. Evolutions in extreme hydrological regimes in France: climate change and Hurst phenomenon. Environmental sciences. 2009
18. Mann HB. Nonparametric tests against trend, *Econometrica*. 1945; 13, 245-259
19. Kendall MG. Rank correlation methods, 202 pp., Griffin, London. 1975
20. Tyson PD, Dyer TG, Mametse MN. Security changes in South African rainfall: 1880 to 1972. *Quarterly Journal of Royal Meteorological Society*. 1975; 101, pp. 817-833.
21. Hamed KH. Trend detection in hydrologic data: The Mann-Kendall trend test under the scaling hypothesis, *Journal of Hydrology*. 2008; 349: 350 - 363. <http://dx.doi.org/10.1016/j.jhydrol.2007.11.009>.
22. Helsel DR, Hirsch RM. Statistical Methods in Water Resources Techniques of Water Resources Investigations, Book 4, Chapter A3. United States Geological Survey. 522 pages. 2002
23. Yue S, Wang CY. The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resources Management*. 2004; 18: 201 - 218.
24. Hamed KH, Rao R. A modified Mann-Kendall trend test for autocorrelated data. *J. Hydrol*. 1998; 204, 182–196.
25. Renard B. - Detection and consideration of possible impacts of climate change on hydrological extremes in France. Thesis of the National Polytechnic Institute of Grenoble . Hydrology-Hydraulic Research Unit, Cemagref (Lyon). 2006
26. Lopez B, Leynet A, Blum A, Baran N. Assessment of trends in pollutant concentrations in groundwater: Review of existing statistical methods and recommendations for the implementation of the WFD. BRGM / RP-59515-FR final report. 2011

27. Hirsch RJ, Slack R, Smith. Techniques of Trend Analysis for Monthly Water Quality Data, *Water Resources Research*. 1982; 18, 107–121.
28. Alexandersson H. A homogeneity test applied to precipitation data, *Journal of Climatology*. 1986; 6, 661–675.
29. Alexandersson H, Moberg A. Homogenization of Swedish temperature data, I, A homogeneity test for linear trends, *International journal of climatology*. 1997; 17, 25-34.
30. Claudie B, Taha BMJO, Ousmane S, Gilles B, Abderrahmane Y. Bibliographic review of techniques for homogenization of climatic series and analysis of applicability to precipitation series. Research Report No R-811, ISBN: 2-89146-310-2. 2005
31. McGree S, Whan K, Jones D, Alexander LV, Imielska A, Diamond H, et al. An updated assessment of trends and variability in total and extreme rainfall in the western Pacific. *International Journal Climatology*. 2014; 34 (8), 2775–2791. doi: 10.1002 / joc.3874.
32. Amoussou E, Awoye H, Vodounon TSH, Obahoundje S, Camberlin P, Diedhiou A, Kouadio K, Mahé G, Houndénou C, Boko M. Climate and extreme rainfall events in the Mono River Basin (West Africa): investigating future changes with regional climate models. *Water*. 2020; 12, 833. doi: 10.3390 / w12030833.
33. Balme M, Lebel T, Amani A. Dry and wet years in the Sahel: quo vadimus? *Hydrological Sciences Journal of Hydrology Sciences*. 2006; 51 (2), 254-271.
34. Sultan B, Baron C, Dingkuhn M, Sarr B, Janicot S. Agricultural impacts of large-scale variability of the West African Monsoon. *Agricultural and Forest Meteorology*. 2005; 128, 95-110.
35. Marteau R, Sultan B, Moron V, Alhassane A, Baron C, Traoré SB. The onset of the rainy season and farmers' sowing strategy for pearl millet cultivation in Southwest Niger. *Agric. Forest Meteorol.* 2011; 151, 10, 1356-1369, doi: <http://dx.doi.org/10.1016/j.agrformet.2011.05.018>.

36. Aguilar E, Barry AA, Brunet M, Ekang L, Fernandes A, Massoukina M, et al. Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955–2006. 2009
37. Soro GE, Goula BTA, Kouassi FW, Srohourou B. Evolution of intensities annual maximum hourly rains in Ivory Coast African Agronomy. 2010; 22 (1): 33 - 44. French
38. Hamed KH. Effect of persistence on the significance of Kendall's tau as a measure of correlation between natural time series. The European physical journal. 2009; 174: 65 - 79.
39. Yue S, Wang CY. Assessment of the significance of serial correlation by the bootstrap test. Water Resour. Manage. 2002; 16, 23–35.
40. Yedjinnavènan Ahokpossi. Analysis of the variability and evolution of precipitation in the Republic of Benin (West Africa), Hydrological Sciences Journal. 2018; 63: 15-16, 2097 2123.
41. Hulme M. Climate change in Africa: 1900–2100. Climate research. 2001; 17 (2 SPECIAL 8), 145 - 168. doi: 10.3354 / cr017145.
42. Nicholson SE. The West African Sahel: a review of recent studies on the rainfall regime and its interannual variability. ISRN Meteorol 2013: 32. <https://doi.org/10.1155/2013/453521>.
43. Goula BTA, Savane I, Konan B, Fadika V, Kouadio GB. Impact of climate variability on the water resources of the N'Zo and N'Zi basins in Ivory Coast (humid tropical Africa). Vertigo. 2006; n ° 1, pp. 1-12.
44. Kouakou KE, Goula BT A, Savané I. Impacts of climatic variability on surface water resources in humid tropical zones: Case of the transboundary watershed of Comoé (Ivory Coast - Burkina Faso). European Journal of Scientific Research. 2007; 16 (1), pp. 31-43.
45. Kanohin F. Evolution of surface and underground water resources in a context of climatic variability in the region of Daoukro (Center-East of the Ivory Coast). Unique doctoral thesis, Abobo-Adjamé University, Abidjan (Ivory Coast), 146 p. 2010

46. Goula ABT, Soro GE, Kouassi W, Srohourou B. Trends and ruptures in extreme daily rains in Côte d'Ivoire (West Africa). *Hydrological Sciences Journal*. 2012; 57 (6), 1067–1080.
47. Ozer P, Hountondji Y C, Gassani J, Djaby B, DE Longueville F. Recent trends in rainfall extremes in Mauritania (1933–2010). Edited by. In: XXVIIth Colloquium of the International Association of Climatology, July 2–5, 2014, Dijon. University of Burgundy, 394–400.
48. Spinoni J, Gustavo N, Hugo C, Paulo B, Jürgen V. Frequency, duration and severity of global droughts for 1951-2010. *International Journal of Climatology*. 2014 ; 34 (8), 2792 - 2804. doi: 10.1002 / joc.3875.
49. Soro TD, Soro N, Oga YM-S, Lasm T, Soro G, Ahoussi KE, Biemi J. Climate variability and its impact on water resources in the square degree of GrandLahou (southwest of Côte d'Ivoire), *Physio-Géo*. 2011; 5, pp. 55-73.

UNDER PEER REVIEW