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Abdouramane AMADOU

Statistical analysis and flood frequency analysis for conceiving flood management Options in the Volta Basin (Case of Nakambe River Sub-Basin in Burkina Faso)

Defended on 17/09/2019 Before the Following Committee:

Chair	Imen Marok-Guasmi	Dr	University of Tlemcen
Supervisor	Bernard TISCHBEIN	Dr	Zef, University of Bonn
External Examiner	Karima BENHATTAB	Dr	USTO, ORAN
Internal Examiner	Hamid BOUCHELKIA	Dr	University of Tlemcen

DECLARATION

I, AMADOU Abdouramane, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

Date: 02/09/2019

Signed Amadou Abdouramane

AMADOU Abdouramne

CERTIFICATION

This thesis has been submitted with my approval as the supervisor

Signed Date: 04th September 2019

Dr Bernard TISCHBEIN

Zef, University of Bonn

B. Tischbein

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ABSTRACT

The advent of climate change raises many questions about the evolution of climatic conditions and their impact on the hydrological regime of rivers. In order to evaluate the different significant variations in temperature, rainfall or stream flow in recent years, statistical tests can detect breaks in the series or linear trends (increase or decrease). This study presents an application of these tests and their conditions of use on the flow data series of four hydrometric stations in the Bagré basin in Burkina faso, obtained from the General Directorate of Water Resources (DGRE) of Ouagadougou. Otherwise the study examined the pattern of flow data based on an Annual Serie Maximum (ASM) method in the basin, estimated and predicted flood return periods and the associated magnitude of river flow.

In the light of this study, significant evolutions or breaks are highlighted, the method does not make it possible to determine their causes and to attribute them a climatic or anthropic origin for example.

Key Words: Statistical test, Flood, Return Period, Bagré Basin, Burkina Faso

RESUME

L'avènement du changement climatique soulève de nombreuses questions sur l'évolution des conditions climatiques et leur impact sur le régime hydrologique des rivières. Pour évaluer les différentes variations significatives de la température, des précipitations ou du débit des cours d’eau au cours des dernières années, des tests statistiques peuvent détecter des ruptures dans la série ou des tendances linéaires (augmentation ou diminution). Cette étude présente une application de ces tests et de leurs conditions d'utilisation à la série de données de débit de quatre stations hydrométriques du bassin de Bagré au Burkina Faso, obtenue de la Direction générale des ressources en eau (DGRE) de Ouagadougou. Dans le cas contraire, l’étude a examiné la configuration des données de débit basée sur la méthode de la série annuelle maximale (ASM) dans le bassin, les périodes de retour d’inondation estimées et prévues et la magnitude associée du débit de la rivière.

A la lumière de cette étude, des évolutions ou ruptures significatives sont mises en évidence, la méthode ne permettant pas de déterminer leurs causes et de leur attribuer une origine climatique ou anthropique par exemple.

Mots-clés : test statistique, inondation, période de retour, bassin de Bagré, Burkina Faso

ABBREVIATIONS AND ACRONYMS

AIC: Akaike Information Criteria

AMS: Annual Maximum Series

BIC: Bayesian Information Criteria

DGRE: Direction Général des Ressources en Eau

EVA: Extreme Values Analysis

PDS: Partial Duration Series

1 INTRODUCTION

1.1 Background

Various studies highlight changes in temperature, rainfall or stream flow in the recent period. The extent and reality of these developments depend on the regions and hydro-climatic conditions. For flows, it is also not always easy to establish whether the origin of the evolutions observed is related to climate changes or changes in land use (waterproofing), agricultural practices. In the framework of the establishment of "Climate Plans" or preparation for the implementation of the Flood Framework Directive, decision-makers may be interested in developments expected to expire in 30 or 50 years. This may make it possible to propose local mitigation or adaptation measures, for example to increase the exposure to flood risks.

But before quantifying the magnitude of future developments, a preliminary step is already to establish a diagnosis of past years, based on existing data sets, to identify whether trends are already detectable. To do these statistical tests can detect, over long time series of at least thirty to forty years, breaks (Pettitt test) or linear trends downward or upward (Mann-Kendall test) and evaluate whether the changes are statistically significant. We present in this sheet the principles of use of these tests, their possible framework of use by design offices and their limits. We illustrate their interest using hydrometric flow data collected on the watershed

Faced with the sequence of extreme events such as floods, it is common to invoke climate change or land use changes to explain an increase in these phenomena, without this discourse being always sufficiently supported by the analysis.

On the peri-urban watershed of Nakambe river Basin (Figure 1), since the 1990s, there has been a recrudescence of damaging floods at the outlet. Recent evolutions in this watershed, which has become highly urbanized since the 1970s, with an increase in periurbanization from downstream to upstream, and the associated soil sealing, (Kermadi et al., 2011a), pose the question of the role of urbanization on this recrudescence of floods.

However, before any conclusion, two preliminary questions must be addressed:

- are the evolutions observed statistically significant?

- If yes, what is the probability of these changes in flow data discharge to happen and at which return period.

The flow data for this basin were therefore analyzed using the Pettitt and Mann-Kendall statistical tests to obtain initial answers to these two questions (Kermadi et al., 2011b, Braud et al., 2011).

1.2 Statement of problem

At least 34 people have died in northern Ghana in floods caused by heavy rains and overflows from a dam in neighboring Burkina Faso, relief agency officials said Thursday.

"In total, we have 34 dead and two missing, more than 52,000 people have been affected," said Seji Saji, deputy head of Ghana's National Disaster Management Organization.

The Bagré Dam, one of the largest in Burkina Faso, on the right bank of the Nakambé River (formerly White Volta), has a holding capacity of over one billion m3 of water. It is 30 km from the Ghana border. The Burkinabè authorities open the dam gates during the rainy season, but the excess water volumes regularly flood the areas along the rivers.

The Ghanaian authorities have recommended villagers near the Nakambé River to move away from the shoreline or temporarily settle on high ground.

Ghana's President Nana Akufo-Addo and her government have been criticized for not visiting the flood victims. The situation demanded "high-level political attention," said Zakaria Sulemana, head of Oxfam in Ghana(*http://www.lefigaro.fr)*

. At the sub-regional level, contrary results were obtained over the same period (by MAHE et al. (2005) who worked in the Nakambé basin in Burkina Faso (Sahel).

In a context of declining rainfall and an increase in the number of dams, these authors observe a significant increase in flows during the months of July, August and September and especially a displacement of the peak from September to August. They explain that changes in land use have ultimately increased runoff at basin level. The natural vegetation which occupied 43% of the basin in 1965 was only 13% in 1995 while the agricultural area increased from 53% to 76% of the total area.

area of the basin and that the area of bare soil has tripled from 4% to 11% of that of the basin. Other studies have shown similar results in the Sahelo-Sudanian region, particularly in Niger and Burkina Faso (LUDUC et al., 2000 in MAHE et al., 2005, MAHE et al., 2003).

Spills made by the dam manager cause a rise in the water level downstream, resulting in a sudden increase in maximum flows. Indeed, the riverside populations questioned underlined the sudden nature of the floods after the construction of the dam. But, given the results, this is not enough to say that downstream flooding is the result of the hydroelectric dam. These are rather the cause of the rainfall improvement in the whole basin since the end of the 80s which coincided with the construction of the dam. In addition, we have shown that the maximum flows measured downstream are still far lower than they were before the construction of the

hydroelectric dam, despite "spill" spills when the reservoir is full. It is a coincidence of climatic and anthropic events.

1.3 Objective of Study

Specific objectives:

- establishing a statistical test analysis to determine trends and breakpoints in the annual maximum series time of discharge data.
- Developing a frequency analysis of the flow rates, determine the best probability of distribution for each station and estimate the return periods of different discharges.
- Recommending some adaptation and flood prevention measures

1.4 Structure of report

This study is divided into seven chapters. Chapter 1 provide a brief introduction and the the objectives of the work. Chapter presents the literature review on statistical analysis tests, flood frequency analysis. Chapter three present the area study. Chapter four outlines the methodology and procedures of each tools used in this research indicate the data sources. Chapter five presents the different results and discussions. In chapter six, adaptation and prevention measures are highlighted. Chapter seven presents conclusion and recommendations. In addition to this, appendixes are attached at the end.

2 LITERATURE REVIEW.

2.1 Background

2.1.1 Extreme value models

For evaluating the risk of extreme events, a parametric frequency analysis approach is adopted in EVA. This implies that an extreme value model is formulated based on fitting a theoretical probability distribution to the observed extreme value series. Two different extreme value models are provided in EVA, the annual maximum series (AMS) method and the partial duration series (PDS) method, also known as the peak over threshold (POT) method.

2.1.2 Basic probabilistic concepts

The defined extreme value population is described by a stochastic variable X. The cumulative distribution function F(x) is the probability that X is less than or equal to x

$$F(x) = P\{X \leq x\} \qquad (1)$$

The probability density function f(x) for a continuous random variable is defined as the derivative of the cumulative distribution function

$$f(x) = \frac{dF(x)}{dx} \qquad (2)$$

The quantile of a distribution is defined as

$$x_p = F^{-1}(P) \qquad (3)$$

where $p = P\{X \leq x\}$. The quantile X_p is exceeded with probability (1-p), and hence is often referred to as the (1-p)-exceedance event. Often the return period of the event is specified rather than the exceedance probability. If (1-p) denotes the exceedance probability in a year, the return period T is defined as

$$T = \frac{1}{1-P} \qquad (4)$$

Correspondingly, the T-year event xT calculated from (2.3) is the level, which on the average is exceeded once in T years.

2.1.3 Annual maximum series

In the annual maximum series (AMS) method the maximum value in each year of the record are extracted for the extreme value analysis (see Figure 2.1). The analysis year should preferably be defined from a period of the year where extreme events never or very seldomly occur in order to ensure that a season with extreme events is not split in two. Alternatively, a specific season may be defined as the analysis year.

For estimation of T-year events, a probability distribution F(x) is fitted to the extracted AMS data $\{X_i,\ i = 1,2,\dots,n\}$ where n is the number of years of record. The T-year event estimate is given by:

$$\hat{x}_T = F^{-1}\left(1 - \frac{1}{T};\ \hat{\theta}\right) \qquad (5)$$

Where $\hat{\theta}$ are the estimated distribution parameters.

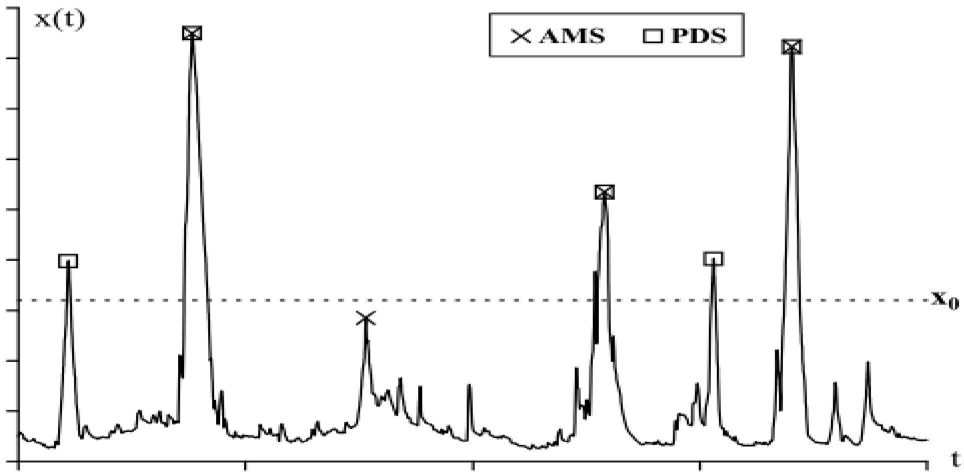


Figure 1:Extraction of AMS and PDS from the recorded time series

2.1.4 Partial duration series

In the partial duration series (PDS) method all events above a threshold are extracted from the time series (see Figure 2.1). The PDS can be defined in two different ways. In Type I sampling, all events above a predefined threshold x0 are taken into account $\{xi > x0, i = 1,2,\dots,n\}$, implying that the number of exceedances n becomes a random variable. In Type II sampling, the n largest events are extracted $\{x_{(1)} \geq x_{(2)} \geq \dots \geq x_{(n)}\}$, implying that the threshold level becomes a random variable. If n equals the number of observation years, the PDS is referred to as the annual exceedance series.

In EVA, both the Type I and Type II sampling methods are provided as pre-processing tools for extracting the PDS. If Type I sampling (fixed threshold level) is chosen, the corresponding number of exceedances is calculated. Similarly, if Type II sampling is chosen (fixed number of events or, equivalently, fixed average annual number of events), the corresponding threshold level is determined. For the definition of the PDS, both the threshold level and the average annual number of events have to be specified.

To ensure independent events in the PDS, usually, some restrictions have to be imposed on the time and level between two successive events. In EVA, an interevent time and interevent level criterion can be defined:

– Interevent time criterion Dtc: two successive events are independent if the time between the two events is larger than Dtc.

– Interevent level criterion pc $(0 < pc < 1)$: two successive events are independent if the level between the events becomes smaller than pc times the lower of the two events.

If both criteria are chosen, two successive events are independent only if both (1) and (2) are fulfilled.

If a fixed threshold level is used to define the extreme value series (Type I sampling), the PDS model includes two stochastic modeling components, respectively, the occurrence of extreme events and the exceedance magnitudes. It is assumed that the occurrence of exceedances can be described by a Poisson process with constant or one-year periodic intensity, implying that the number of exceedances n is Poisson distributed with a probability function

$$P\{N(t) = n\} = \frac{(\lambda t)^n}{n!} exp(-\lambda t) \quad (6)$$

where t is the recording period. The Poisson parameter l equals the expected number of exceedances per year and is estimated from the record as

$$\hat{\lambda} = \frac{n}{t} \quad (7)$$

For modeling the exceedance magnitudes, a probability distribution $F(X - X_0)$ is fitted to the exceedance series $\{X_i - X_0, i = 1,2, \dots, n\}$. The T-year event estimate is given by

$$\widehat{x_T} = x_0 + F^{-1}\left(1 - \frac{1}{\widehat{\lambda T}}; \hat{\theta}\right) \qquad (8)$$

Where $\hat{\theta}$ are the estimated distribution parameters.

In the case of Type II sampling, the average annual number of events l is fixed. For modelling the extremes, a probability distribution $\mathrm{F(x)}$ is fitted to the extreme value series $\{\mathrm{xi, i} = 1,2, \dots, \mathrm{n}\}$. The T-year event estimate is given by

$$\widehat{x_T} = F^{-1}\left(1 - \frac{1}{\lambda T}; \hat{\theta}\right) \qquad (9)$$

Where $\hat{\theta}$ are the estimated distribution parameters.

The T-year event in the PDS can also be related to the return period of the corresponding annual maximum series (denoted annual return period T_A). The relationship between the return period T defined above and T_A is given by

$$\frac{1}{T_A} = 1 - \exp\left(-\frac{1}{T}\right) \qquad (10)$$

Note that for return periods larger than about 10 years T and T_A are virtually identical.

2.1.5 Extreme value analysis

The Hyfran software comprises a comprehensive suite of routines for performing extreme value analysis. These include:

- Support of two different extreme value models, the annual maximum series model, and the partial duration series model.
- Support of a large number of probability distributions, including exponential, generalized Pareto, Gumbel, generalized extreme value, Weibull, Frechét, gamma, Pearson Type 3, Log-Pearson Type 3, log-normal, and square-root exponential distributions.
- Three different estimation methods: method of moments, maximum likelihood method, and method of L-moments.

- Three validation tests for independence and homogeneity of the extreme value series.
- Calculation of five different goodness-of-fit statistics.
- Comprehensive graphical tools, including histogram and probability plots.

2.2 Statistical analysis test

2.2.1 Principle of a Statistical Test

A statistical test is to make a decision based on information collected on a sample (Lemaitre, 2002). The tests are to determine if a characteristic (average or standard deviation) taken from a sample, is identical to a reference (standard) or that of another sample. A statistical series can be characterized by two types of parameters: i) position parameters (median, average, ...): they give the order of magnitude of the observations and are related to the central tendency of the distribution and ii) dispersion parameters (standard deviation, variance, coefficient of variation): they show how observations fluctuate around the central tendency (Mestre, 2000). Ordinarily, tests are ranged in two categories: i) the parametric tests that test the value of a certain parameter, in this case, the characteristics of the data can be summarized using the estimated parameters of the sample, subsequent testing procedure bears then on these parameters and ii) nonparametric tests that do not involve parameters and make no hypothesis on the distribution of variables; the prior step is to estimate the parameters of the distributions before proceed to hypothesis test itself. Whatever the test category used, the goal is to decide between two hypotheses, one called null or fundamental (denoted by H0) and other called alternative (denoted by H1). A hypothesis is an attempt to explain how a phenomenon works or approach consisting of the assessment based on a data set (sample). In general, the null hypothesis corresponds to a stationary situation while the alternative hypothesis reflects a change (break or trend) (Lubes and al., 1998). The fundamental notion on testing, the probability that one has to be wrong. There are two ways to go wrong in a statistical test: i) wrongly reject the null hypothesis H0 when it is true: it is the first type of risk (or Type I error) and in general there is the probability α of being wrong in this direction and ii) accept the null hypothesis when it is false: it is the risk of the second kind (or type II error) and in general there is the probability of β err in that direction. The ideal solution is to minimize these types of errors, but in a sample, if we reduce the a, increases the other (Lubes et al., 1994). In practice we minimize the error type I, this type of error is assigned a probability α. This is the probability of making the Type I error is called the level of significance of the test; it helps to define the test of confidence. Knowing this probability α, we can deduce that for the error of β type II which is of the form (1 - α) (Bobée, 1978). The different stages of a statistical test are:

- to define the null H0 (hypothesis testing) and the alternative hypothesis;
- calculating the value of the decision variable from the data;
- define the level of significance of the test (denoted α);
- read on the table the reference value of the variable depending on the test used and
- take a decision regarding the assumption made and make an interpretation: it is to reject or accept the null hypothesis H0. (Fig.2) shows the summary diagram.

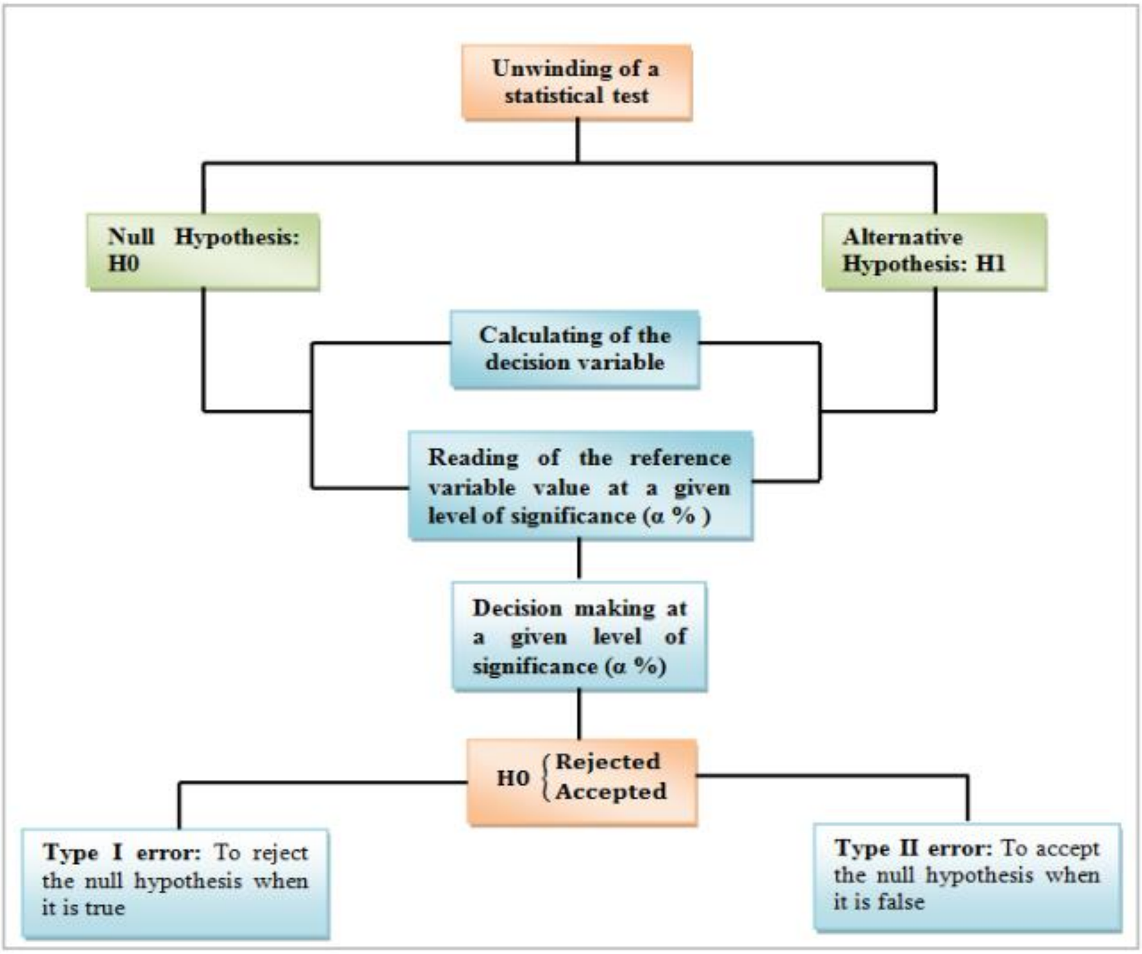


Figure 2: Organization of statistical test

2.2.2 Independence and homogeneity tests

The basic requirements for the extreme value models outlined above are that the stochastic variables Xi are independent and identically distributed. For testing independence and homogeneity of the observed extreme value series, three different tests are available in EVA

- Run test;
- Mann-Kendall test;
- Mann-Whitney test.

2.2.2.1 Run test

The run test is used for general testing of independence and homogeneity of a time series. From the time series $\{Xi, i \ = \ 1,2, \dots, n\}$ the sample median xmed is calculated and a shifted series $\{Si \ = \ xi?xmed, i \ = \ 1,2, \dots, n\}$ is constructed. From the shifted series a run is defined as a set of successive elements having the same sign. The test statistic is given as the number of runs of the shifted series, i.e.

$$z = \sum_{i=2}^{n} sgn(i) \quad , \quad sgn(i) = \begin{cases} 1, & S_{i-1}S_i < 0 \\ 0, & S_{i-1}S_i > 0 \end{cases} \qquad (11)$$

The test statistic is asymptotically normally distributed with mean m_z and variance S_{z^2} given by

$$\mu_z = \frac{n}{2} + 1$$

(12)

$$\sigma_z^2 = \frac{n(n-2)}{4(n-1)}$$

Thus, the standardized test statistic

$$z = \begin{cases} \frac{z-\mu_z-1/2}{\sigma_z}, z > \\ \mu z 0, z = \mu_z \\ \frac{z-\mu_z+1/2}{\sigma_z}, z < \mu_z \end{cases} \qquad (13)$$

is evaluated against the quantiles of a standard normal distribution. That is, the H0 hypothesis of independent and homogeneous data is rejected at significance level a if

$|\dot{z}| > \Phi^{-1}(1 - a/2)$ where $\Phi^{-1}(1 - a/2)$ is the (1-a/2) -quantile in the standard normal distribution.

2.2.2.2 Mann-Kendall test

The Mann-Kendall test is used for testing the monotonic trend of a time series $\{xi, i = 1,2,..,n\}$. The test statistic reads

$$z = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_f - x_i) \qquad (14)$$

Where

$$sgn(x_j - x_i) = \begin{cases} 1 & ,x_j > x_i \\ 0 & ,x_j = x_i \\ -1 & ,x_j < x_i \end{cases} \qquad (15)$$

A positive value of z indicates an upward trend, whereas a negative value indicates a downward trend. The test statistic is asymptotically normally distributed with zero mean $(mz = 0)$ and variance is given by

$$\sigma_z^2 = \frac{1}{18} n(n-1)(2n+5) \qquad (16)$$

For evaluating the H0 hypothesis: no trend in the series, the standardized test statistic calculated from (13) is compared to the quantiles of a standard normal distribution.

2.2.2.3 Mann-Whitney test

The Mann-Whitney test is used for testing shift in the mean between two sub- samples defined from a time series $\{xi, i = 1,2,..,n\}$. For the time series ranks Ri are assigned from $Ri = 1$ for the smallest to $Ri = n$ for the largest observa- tion. Time series of ranks for the two-subsamples are then defined by $\{Ri, i = 1,2,..,n1\}$ and $\{Ri, i = 1,2,..,n2\}$ where n = n1 + n2. The test statistic is given as the sum of ranks of the smaller sub-series, i.e.

$$z = \sum_{i=1}^{m} R_i \quad , \quad m = Min\{n_1, n_2\} \qquad (17)$$

The test statistic is asymptotically normally distributed with mean and variance

$$\mu_z = \frac{m(n+1)}{2}$$

$$\sigma_z^2 = \frac{n_1 n_2 (n+1)}{12} \qquad (18)$$

For evaluating the H0 hypothesis: the same mean value in the two sub-series, the standardized test statistic calculated from (13) is compared to the quantiles of a standard normal distribution.

2.2.3 Breakage study

This section is devoted to the study of possible breaks in series observed and simulated associated with each of the 21 watersheds. To evaluate the null hypothesis of no break, we used several approaches.

Pettitt's (1979) test is a non-parametric test that detects an average break in a series. (We used the α = 5% and 10% thresholds.) Let us note that the procedure of Kehagias and Fortin (2006) makes it possible to detect several breaks, which is not the case of the tests of Pettitt (1979) and Lombard (1987). On the other hand, Pettitt's (1979) test identifies a single year of failure, whereas Lombard's (1987) test detects an interval during which the rupture occurred. Other procedures exist in the literature to test the presence of a break in a time series and in particular Bayesian approaches (see Perreault et al., 2000b, c), but these approaches are heavier to implement than the tests of Pettitt (1979) and Lombard (1987) that we have used.

It should be noted that the presence of significant fracture (s) at the 5% [resp., 10%] threshold is indicated in yellow [resp., In blue]. In the following, we will say that a break is significant on average when at least one of the two tests (Pettitt and Lombard with L (¯x)) is significant. "These two tests do not always lead to the same conclusion.

to the approximation used for the calculation of the threshold in the case of the Lombard (1987) test "

Note, however, that when several procedures detect an average break, they detect it for the same year, except perhaps for BAL observations.

2.2.4 Trend study

To test the null hypothesis of no trend, we used two approaches.

- The adjustment of a linear regression model between the annual flows (explained variable) and the time (explanatory variable) allows us to perform a slope significance test which corresponds to a trend test (linear).). This test is parametric since it assumes the usual assumptions of a regression model, and in particular normality.

- The Mann-Kendall test, proposed by Mann (1945) and Kendall (1975), is non-parametric and allows a priori to detect non-necessarily linear trends.

We have identified in yellow [resp., In blue] the cases where the null hypothesis of absence of trend is rejected at the nominal threshold $\alpha = 5\%$ [resp., 10%]. We say that a trend is significant when the two implanted tests lead to this conclusion. The examination of the figure, however, suggests that it is rupture that induces a significant trend.

2.3 Goodness-of-fit statistics

For evaluating the fit of different distributions applied to the extreme value series, EVA calculates five goodness-of-fit statistics.

- Chi-squared test statistic
- Standardized least squares criterion
- Probability plot correlation coefficient
- Log-likelihood measure

It must be emphasized that the choice of probability distribution should not rely solely on the goodness-of-fit. The fact that many distributions have a similar form in their central parts but differ significantly in the tails emphasizes that the goodness-of-fit is not sufficient. The choice of a probability distribution is generally a compromise between contradictory requirements. Selection of a distribution with few parameters provides robust parameter estimates but the goodness-of-fit may not be satisfactory. On the other hand, when selecting a distribution with more parameters, the goodness-of-fit will generally improve but at the expense of a large sampling uncertainty of the parameter estimates.

Besides an evaluation of the goodness-of-fit statistics, a graphical comparison of the different distributions with the observed extreme value series should be carried out. In this respect the histogram/frequency plot and the probability plot are useful. These plots are described in Section 8.

2.3.1 Chi-squared test statistic

The X^2-test statistic is based on a comparison of the number of observed events and the number of expected events (according to the specified probability distribution) in class intervals covering the range of the variable. The test statistic reads

$$z = \sum_{i=1}^{k} \frac{(n_i - np_i)^2}{np_i} \qquad (19)$$

where k is the number of classes, ni is the number of observed events in class i,

n is the sample size, and p_i is the probability corresponding to class i, implying that the number of expected events in class i is equal to np_i. The test is more powerful if the range of the variable is divided into classes of equal probability, i.e. $p = 1/k$. The corresponding class limits for the considered distributions are obtained from the quantile function cf. (1.3). The number of classes is determined such that the expected number of events in a class is not smaller than 5.

The test statistic is approximately x^2-distributed with $k - 1 - q$ degrees of freedom where q is the number of estimated parameters. Thus, the H_0 hypothesis that data are distributed according to the specified probability distribution is rejected at significance level a if $z > x^2(k-1-q)_{1-a}$ where $x^2(k-1-q)_{1-a}$ is the $(1-a)$-quantile in the x^2-distribution with $k - 1 - q$ degrees of freedom.

2.3.2 Standardized least squares criterion

The standardized least squares criterion (SLSC) and the probability plot correlation coefficient described in Section 6.4 are both based on the difference between the ordered observations and the corresponding order statistics for the considered probability distribution. The SLSC is defined using a reduced variate U_i (Takasao et al., 1986)

$$U_i = g(x_i\ ;\theta\ ) \qquad (20)$$

where g(.) is the transformation function, and q are the distribution parameters. For the ordered observations $X_{(1)} \geq X_{(2)} \geq \cdots \geq X_{(n)}$, the reduced variates U_i are calculated from (20) using the estimated parameters. The corresponding order statistics are given by

$$u_i^* = g(F^{-1}(p_i)) \qquad (21)$$

where p_i is the probability of the $i'th$ largest observation in a sample of n variables.

The probability is determined by using a plotting position formula (see Section 8).

The SLSC is calculated as

$$z = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(U_{(i)} - U_i^*)^2}}{|U_{1-p}^* - U_p^*|} \qquad (22)$$

where u_{1-p}^* and u_p^* are the reduced variates calculated from (22) using non-

exceedance probabilities $1 - p$ and p, respectively. The denominator in (23) is introduced in order to standardize the measure so that the SLSC can be used to compare goodness-of-fit between different distributions. Smaller values of SLSC correspond to better fits. In EVA, $p = 0.01$ is used for the calculation of SLSC.

Formulae of the reduced variates and corresponding order statistics for the distributions available in EVA are given in Appendix A. For some distributions several formulations of the reduced variate have been proposed. In EVA, the SLSC1 formula is used as the main output, whereas the other SLSC measures are given as supplementary output. It should be noted that for a consistent and more direct comparison between different distributions, the same reduced variate should be used, if possible. For instance, for comparing the goodness-of-fit between the Gumbel, Frechét, generalized extreme value, and square-root exponential distributions the SLSC measure based on the Gumbel reduced variate $U_i = -\ln[-ln(p_i)]$ should be applied. For comparison of the exponential, generalized Pareto, and Weibull distributions the exponential reduced variate $U_i = -\ln(1 - p_i)$ should be used.

The distribution of the SLSC statistic depends, in general, on the considered distribution, the estimated parameters, the estimation method, and the sample size. Thus, no general table for critical values of the test statistic exists.

In certain situations, some data points may fall outside the estimated range of the considered distributions (e.g. some observations are smaller (or larger) than the estimated location parameter), implying that the reduced variate is not defined. In EVA, these points are not included in the calculation of the SLSC measure. In such cases, one should be careful in using the SLSC measure for comparing the goodness-of-fit of various distributions.

2.4 Description of Khronostat Model Khronostat

Khronostat is a statistical model developed by IRD (Research Institute for Development) at the House of Water Sciences (MSE) of Montpellier. It was developed as part of a study on climate variability in West and Central Africa and is oriented on the analysis of hydroclimatic series (Boyer, 2002). It can evolve on an annual, monthly or daily scale depending on the needs expressed. Khronostat includes within it various statistical tests:

- ➢ the first test category concerns the randomness (or independence test) series (correlation test on the rank and autocorrelogram test): they carry to the constancy of the average of the series throughout its observation period and
- ➢ the second test category concerns the homogeneous character of the series (Pettitt test, Buishand test, Hubert test, Bayesian methods or Lee & Heghinian test): they relate to the detection of breaks in a time series (Paturel, 1995). These tests, whose application conditions are not very strict:

- – allow to characterize as well as possible the evolution of climate parameters;
- – identify the pivotal years of climate change;
- – complement climatic index calculations and
- – define the causes of series heterogeneity by sudden changes in climate series. Khronostat is adapted to all variables (climatic, hydrological, meteorological...).

However, it requires complete series with no gaps. Its choice in this study is justified by the robustness of its tests and also by its success through several similar studies in sub-Saharan Africa. It is also well advised by the meteorologists and climatologists over the world for surveillance or monitoring of drought.

2.4.1 Independence Test

The independence test is used to test the likelihood of no bond in a population from a sample. It provides information on the strength of the evidence and not on the strength of the association. The most common tests relate to the constancy of the average of the series throughout its period of observation (L'hote and al., 2002). These tests are powerful enough in general to distinguish between random and non-random nature of the series. The independent tests used in this article available in Khronostat are: the correlation test of rank and test the Autocorrelogram. For all these tests, the null hypothesis that must be tested is H0 «the series is random» (Bop, 2008).

2.4.2 Autocorrelogram Test

The estimation of the autocorrelogram is the first step in the statistical analysis of time series. The autocorrelation coefficient of order k is given by the following expression: The autocorrelation coefficient of the K_{th} order is given by the equation (1) (Lubès et al., 1994):

$$r_k = \frac{\sum_{i=1}^{N-k}(X_i - \bar{X}_1)(X_{i+k} - \bar{X}_2)}{\sqrt{\sum_{i=1}^{N-k}(X_i - \bar{X}_1)^2 \sum_{i=1}^{N-k}(X_{i+k} - \bar{X}_2)^2}} \qquad (24)$$

The averages X 1 and X 2 are determined for each value of k by equations (25) and (26).

$$\bar{X}_1 = \frac{1}{N-k}\sum_{i=1}^{N-k} X_i \qquad (25)$$

$$\bar{X}_2 = \frac{1}{N-k}\sum_{i=k+1}^{N} X_i \qquad (26)$$

The graph $rk = f(k)$ represent the autocorrelogram. The series is called random when, for large N, the autocorrelation coefficient rk, has a value close to zero for all values of k nonzero. We can then determine a confidence interval containing the autocorrelogram in the case of a random series. The null hypothesis is to assume that the sample elements are independent H0 "the elements of the series are independent." For a given confidence level α, we give the confidence interval of the autocorrelogram as follows (4) (Bop, 2008):

$$-\frac{u_{(1-\frac{\propto}{2})}}{\sqrt{N}} < r_k < \frac{u_{(1-\frac{\propto}{2})}}{\sqrt{N}} \qquad (27)$$

U is the standard normal variable obtained from the Student table with one degree of freedom N-2. The series is considered random if all or most of rk values are within the confidence interval of the autocorrelogram.

2.4.3 Correlation Test of Rank

The correlation test in the row to determine the number of pairs of Xi and Xj such as $Xj > Xi$, for $j > i$. Under the null hypothesis H0 «the series is random» for a given level of significance

$\alpha = 5\%$. The standard score U is given by equation (28) (IRD-Orstom, 1998):

$$U = \frac{\dot{r}}{\sqrt{var(\dot{r})}} \qquad (28)$$

The test is based on the statistical defined by equation (29):

$$\dot{r} = \frac{4Nc}{N(N-1)} - 1 \qquad (29)$$

In this expression, Nc represents the number of pairs of consecutive observations (X_i, X_j) as $X_i > X_j$; $j > i$; $with\ (i = 1, j = 2, N), (i = 2, j = 3, N), \ldots, (i = N-1, j = N)$.

The variance $var(\dot{r})$ is given by the relation (7) (Boyer, 2002):

$$var(\dot{r}) = \frac{2(2N+5)}{9N(N-1)} \qquad (30)$$

Under the null hypothesis of a random series, the reduced centered variable U tends to follow a normal distribution when N increase. The null hypothesis is accepted when we have:

$$U_{\frac{\propto}{2}} < U < U_{1-\frac{\propto}{2}}$$

In the case of a tail test, the null hypothesis is accepted when:

$|U| < U_{1-\frac{\propto}{2}}$ with $U_{1-\frac{\propto}{2}} = 1.96$ for a sample size (N> 230)

When the series is not random, it can admit a tendency or a periodicity.

2.5 Homogeneity Test

A sample is said to be homogeneous if it presents no breaks. A break can be generally defined as an abrupt change in the probability law of the series at a given time, usually unknown. It corresponds to a trend reversal of the time series (Traore and al., 2014). The break detection tests used in this article and available in Khronostat, are: Pettitt test, Buishand test, Hubert test and Lee and Heghinian test. For all these tests, the null hypothesis that must be tested is H0 « no break in the series » (Paturel, 1995).

2.5.1 Pettitt Test

The Pettitt approach is non-parametric and is derived from

the Mann-Whitney test. The absence of break in the series (xi) of size N is the null hypothesis. The use of the test supposes that for any time t with a value between 1 and N, the two-time series (Xi) for $i = 1$ to t and for $i = t + 1$ to N belong to the same population. The variable that is to be tested is K_N, the maximum in absolute terms of the variable $U_{t,N}$ defined by the relation (8) (L'hote and al., 2002):

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=t+1}^{N} D_{i,j} \qquad (31)$$

Where $D_{i,j}$ is the coefficient given by equation (9)

$$D_{i,j} = sgn(x) = sgn(X_i - X_j \qquad (32)$$

with $sgn(x) = 1$ if $X > 0, if\ x = 0$ and -1 $if\ x < 0$.

If k is the value of KN taken on the studied series, under the null hypothesis, then the probability of exceeding of the value k is given approximately by equation (33) (Rosine et al., 2015):

$$prob(K_N > K) \approx 2exp\left[-\frac{6K^2}{N^2+N^3}\right] \qquad (33)$$

If Prob ***(K > k) < α*** for a significance level α, then the

null hypothesis is rejected, then an estimation of the date of the break is provided by the moment t defining the maximum in absolute terms of the $U_{t,N}$ variable.

2.5.2 Buishand Test

The Buishand procedure refers to the same model and to the same hypotheses as the Lee and Heghinian approach. If the assumption is that there is a uniform distribution for the position of the break point t, the Buishand U statistic is defined by equation (11) (Rosine and al., 2015):

$$U = \frac{\sum_{k=1}^{N-1} (S_k / \sigma_x)^2}{N(N+1)} \quad (34)$$

Where the terms S_k and σ_x are respectively partial sum and standard deviation given respectively by equations (35) and (36):

$$S_k = \sum_{i=1}^{k} (X_i - \bar{X}) \quad (35)$$

$$\sigma_x^2 = \frac{1}{N} \sum_{i=1}^{N} (X_i - \bar{X})^2 \quad (36)$$

The null hypothesis of the statistical test is the absence of break in the series. In the case of rejection of the null hypothesis, no estimation of the date of the break is proposed by this test**.** In addition to these different procedures, the building of a control ellipse makes it possible to analyze the homogeneity of the (xi) series. Under the null hypothesis assumption, the SA variable, defined above, follows a normal distribution with a zero mean and a variance equal to equation (14) (Buishand, 1984):

$$\sigma^2 = \frac{1}{N} K(N - K), \text{ with } k = 0 \text{ to } N \quad (37)$$

This control ellipse was used here to estimate visually the importance of the deviations under the null hypothesis of the homogeneity of the series. It is consequently possible to define confidence limits including the series of the Sk.

2.5.3 Hubert Test

Hubert's segmentation procedure detects the multiple breaks in time series. The principle is to cut the series into m segments (m>1) such that the calculated means of the neighboring sub-series significantly differ. To limit the segmentation, the means of two contiguous segments must be different to the point of satisfying Scheffe's test (Hubert, 1987). The procedure gives the timing of the shifts. Giving a mth order segmentation of the time series, $ik\ k = 1,..m$, the rank in the initial series of extreme end of the kth segment $(with\ i_0 = 0)$, the following are defined by equation (38) (Hubert and al., 2007);

$$\bar{X}_k = \frac{\sum_{i_{k-1}+1}^{i_k} X_i}{n_k} \quad (38)$$

D_m is the quadratic deviation between the series and the segmentation given by equation (16)

$$D_m = \sum_{k=1}^{m} \sum_{i_{k-1}+1}^{i_k} (X_i - \bar{X}_k)^2 \quad (39)$$

For a given segmentation order, the algorithm determine the optimal segmentation of a series that is such that the deviation Dm is minimal. This procedure can also be interpreted as a stationary test, the null hypothesis being the studied series is non-stationary. If the procedure doesn't produce acceptable segmentations of order bigger or equal to two, the null hypothesis is accepted (Paturel, 1995).

2.5.4 Lee and Heghinian Test

Lee & Heghinian tests are Bayesian procedures appliedunder the assumption that the studied series is normally distributed. The tests are based on the following model, which supposes a change in the series mean given by equation (10) (L'hote et al., 2002):

$$X_i = \begin{cases} \mu + \varepsilon_i, i = 1, \dots \dots, \tau \\ \mu + \sigma + \varepsilon_i, i = \tau + 1, \dots \dots, N \end{cases} \quad (40)$$

The ε_i are independent and normally distributed, with a mean equal to zero and a variance equal to σ^2, τ and σ represent the position in time and the scope of the possible change in the mean respectively. The method determines the a posteriori probability distribution function of the parameters μ and δ, considering their a priori distributions and supposing that the break time follows a uniform distribution. When the distribution is unimodal, the date of the break is estimated by the mode with all the more accuracy as the dispersion of the distribution is small (Boyer, 2002).

2.6 HYFRAN-PLUS software

Hyfran-Plus software is designed for frequency analysis in hydrology especially for extreme values. However, it can be used for any series of extreme values in other domains with different time steps, provided that the observations are independent and identically distributed (El Adlouni et al, 2006). The HYFRAN-PLUS software makes it possible to adjust a large number of statistical distributions to a series of data that verify the hypotheses of independence, homogeneity and stationarity. A Decision Support System (DSS) has been developed to select the most appropriate class of distributions to estimate the high return period quantile (El Adlouni et al, 2006).

2.7 Flood Frequency /Return Period Analysis

Flood frequency analysis uses historical records of peak flows to produce guidance about the expected behaviour of future flooding. Two primary applications of flood frequency analyses are: to predict the possible flood magnitude over a certain time period and to estimate the frequency with which floods of a certain magnitude may occur (USGS, 2005). The flood frequency analysis is one of the important studies of river hydrology which is conducted based on maximum instantaneous flow (Yadav, 2002).

The recurrence interval or return period is explained as the average time between events of a given magnitude, assuming that different events are random. Common return periods include the 2– 3-5-10– 20–50 and 100 years (USGS, 2008). The recurrence interval or return period of floods of different heights varies from catchment to catchment, depending on various factors such as the climate of the region, the width of the floodplain and the size of the channel. In a dry climate, the recurrence interval of a 3m-height flood might be much longer than in a region that gets regular heavy rainfall (Meyer, 2007). Therefore, the recurrence interval is specific to a particular river catchment. Similarly, based on the works by the USGS (flood return estimations, 2001), the return period is the time period over which it is likely that a particular magnitude flood will occur. Thus, a 25year flood is defined as a flood that can occur on average once every 25 years. In this example, 25 years is considered the return period. However, floods do not occur in exact cyclic events. That is, they do not occur at nicely spaced 25-year intervals as often presumed (USGS, 2011).

Criteria: Two criteria are available, these are the Akaike (AIC) and Bayesian information Criteria (BIC) (see Ehsanzadeh et al., 2010).Criteria can be reliably used in climate statistics to assist in finding the best distribution to use to fit the given data. These tests describe the differences between the observed data values, and the expected values from the distribution being tested (Millington, Das, & Simonovic, 2011).

Model selection is performed by looking for the minimum AIC and BIC values. The probability distribution recording the lower AIC and BIC is the best fitting the data series (Giuliano, Laio, & Montanari, 2009).

$$\mathbf{AICj} = -2ln\,(Lj) + 2pj \qquad (41)$$

Where pj is the number of estimated parameters, and Lj is the likelihood function and n is the sample size.

The Bayesian criterion (BIC) is based on the discrepancy between the model and the parent distribution in a Bayesian framework (Schwarz, 1978). BIC can be computed according to the following relationship:

$$\mathbf{BIC} = -2\,ln(Lj) + ln(n)pj \qquad (42)$$

2.8 Review of Methods

2.8.1 Flood frequency and Return Period Analysis

The return period is the time period over which it is likely that a particular magnitude of flood will occur. Thus, a 100–year flood is defined as a flood that can occur on average once every 100 years. In this illustration, 100 years is considered the return period. However, floods do not occur in exact cyclic events. That is, they do not occur at nicely spaced 100–year intervals. Flood frequency analysis uses historical records of peak flows to produce guidance about the expected behavior of future flooding.

Flood frequency or recurrent period is often done in most flood risk zones in Europe and South-East Asia, using different methods. According to European Procedures for Flood Frequency Estimation (2013), the annual maximum flood series is the maximum volume flow rate passing a particular location (typically a gauging station) during a storm event. This can be measured in m3/sec, and is calculated using the following formula: $Tr = (N + 1)/ M$ (where Tr = Return Period of flooding; N= Peak annual river flow; and M = Rank, according to order of highest flow). Where a number of tributaries exist within the catchment of interest, methods of gauging flows on each watercourse may be necessary.

2.8.2 Statistical Testing and Trend Analysis

In the process of organizing and analyzing time series data, statistical tests are often done to unravel the nature of the variables. Trend analysis are carried out in climate data that have been collected over a period of time to find its statistical significance in terms of rainfall and temperature (Tabari et al., 2011; Mavromatis et al., 2011). The most commonly used method for trend estimation and analysis in hydrology is the Mann-Kendal test. This is usually done by formulating hypotheses: null-hypothesis and alternative hypothesis (Motiee et al., 2009; Mavromatis et al., 2011). The null-hypothesis is formulated with the assumption that there is no trend in the data set, while the alternative hypothesis states that there is a trend. If a linear trend is present in a time series data, then the slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). This means that a linear model $f\ (t)$ can be described as $f\ (t) = Qt + B$, where Q is the slope and B is the constant. Mann-Kendall test is suitable for cases with monotonous trends and with no seasonal or other cycles in the data (Motiee et al., 2009). One advantage of this test is that the data need not conform to any particular distribution (Tabari et al. 2011; Drápela et al., 2011).

3 STUDY AREA

3.1 The Volta River Basin

The Volta River Basin is located in West Africa and covers an estimated area of 400,000 km^2. The Volta basin stretches from approximately latitude 5^o 30' N in Ghana to 14^o 30' N in Mali. The widest stretch is from approximately longitude 5^o 30 W to 2^o 00 E but the basin becomes narrower towards the coast of the Gulf of Guinea. The Volta basin is spread over six West African countries (43% in Burkina Faso, 42% in Ghana, and 15% in Togo, Benin, Cote d'Ivoire and Mali).

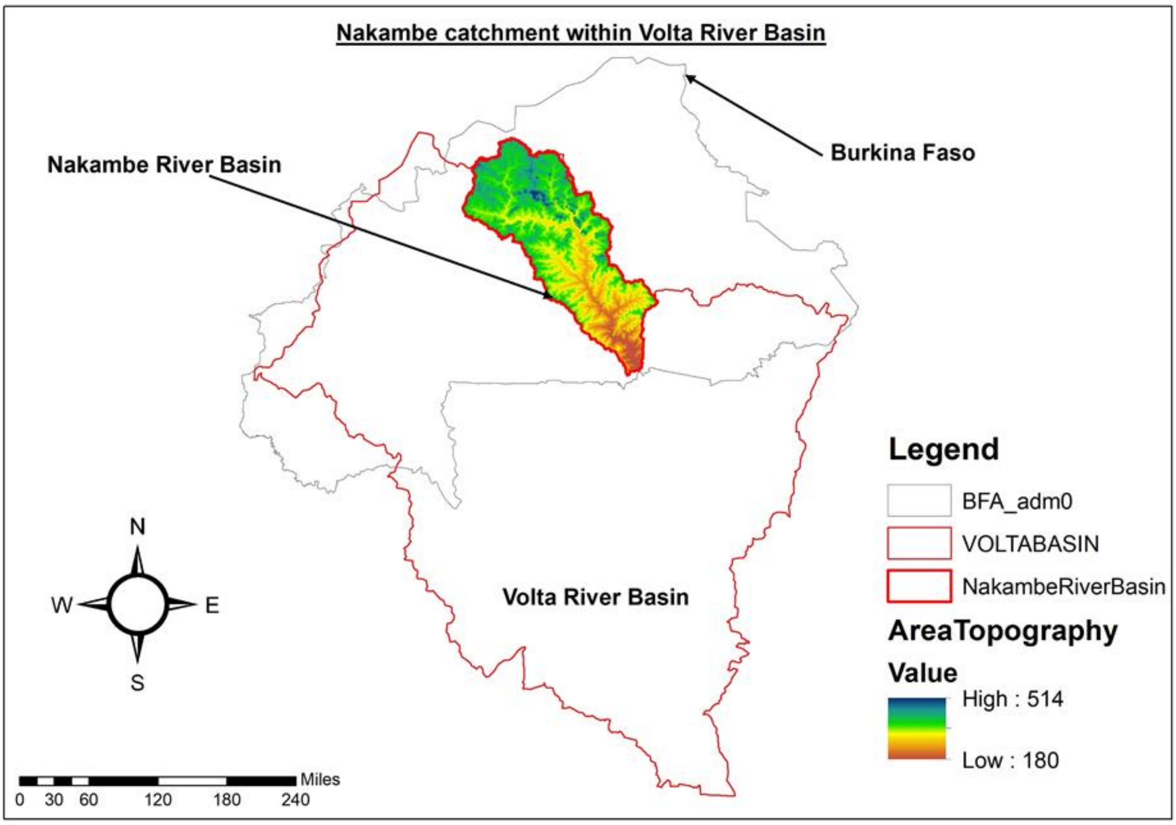


Figure 3: *Nakambe Sub-basin Within Volta River Basin (ArcGIS 10.5)*

Tableau 1 The distribution of the area of the basin among the six riparian countries

Country	**Area of volta river basin (Km^2)**	**% of Basin**	**% of country in the basin**
Benin	17,098	4.10	15.2
Burkina Faso	178,000	42.65	63.0
Côte d'Ivoire	12,500	2.99	3.9
Mali	15;392	3.69	1.2
Togo	26,700	6.40	47.3
Ghana	167,692	40.18	70.0
Total	**417,382**	**100%**	

3.2 Drainage network

The mean annual flows of the White Volta river is 9,565 x 10^6 m^3. The length of its network drainage is about 1,136.7 km with a Run-off coefficient of 10.8%. (See annexe).

3.3 Relief

The White Volta basin in general has a low relief with altitudes varying between 60 and 530m. The average mean altitude of the basin is approximately 270 m, with more than half the basin in the range of 200– 300 m. (*Source: ORSTOM Hydro. Monographs edited by Moniod et al., 1977*.).

3.4 Socio/economic aspects

In Burkina, agriculture is the main activity and it involves mainly food crops, with a clear predominance of cereals. The 1990 MEE/CILSS study which included data for the period covering 1961 to 1988 indicated that the following are the main food crops: sorghum (which takes 51 % of the country's rain-fed cereal area), millet (40 %), maize (6.7 %), rain-fed rice (1.6 %) and fonio (10.7 %).

The main cash crop is cotton, followed by pulses and oil seeds (groundnuts, sesame, cowpea, Bambara bean, etc.), fruits and vegetables (citrus, mango and vegetable products).

In the Nakanbe sub-basin alone (in Burkina) more than 400 dams and small reservoirs have been built over the past years to develop irrigation and generate electricity. Thus, about 47 irrigation schemes have been identified but only 2,620 ha have yet been developed and out of that 1,000 ha are for the Bagre dam alone. An estimated 2,175 ha of inland valleys are to be added to the potential of irrigable land in the basin. Irrigated land in the Nakanbe sub-basin is relatively small compared to the vast potential for irrigation that the large volumes of water stored behind the numerous dams can offer.

3.5 Land use, land ownership and land degradation

In the Nakanbé Basin, land tenure is related to the existing structure. The area is occupied primarily by animal herders who require a large amount of land for pasture, but the land is not used intensively. The land is collectively owned by the group, and they do not have the right to refuse an outsider the use of the land if they have valid reason.

Farming and animal husbandry are significant contributors to land degradation in the basin. Agricultural practices in the basin have in the past included crop rotation and leaving fields fallow for a period of time.

Forested areas are cut to provide additional land for agriculture and animal husbandry, and to provide fuel. Also, timber resources are over-exploited in many parts of the basin. This is done to meet rising demands for foreign exchange, as well as to meet increasing domestic needs.

Land degradation in the basin encompasses soil degradation, intense erosion and desertification. As discussed above, the basin’s population heavily depends on the land resources of the region for subsistence agriculture and livestock breeding.

Land degradation in the region has both transboundary causes and effects. Transhumance, defined as the movement of cattle, sheep, and people across national boundaries, is common within the basin. This phenomenon is usually accompanied by reckless destruction of vegetation, watering sources, etc. The situation also creates social tension and disruption of socio- economic activities, sometimes proving fatal.

3.6 Nakambe River basin

Burkina Faso has a total mean annual precipitation volume of 165 km^3, of which only 9 km^3 is runoff. The country has eight large dams in operation, of about 2100 dams in total. The total storage volume of all reservoirs is approximately 4.6 km^3 The hydrographic network of the country is characterised by three great river basins: the basins of the rivers Nazinon, Nazinga and Mouhoun, of the River Comoé and the River Niger.

The rivers Mouhoun (Black Volta) and Nakanbé (White Volta) constitute the two main sub-basins of the Volta Basin in Burkina Faso. The country has other smaller rivers – the Bougouriba, Comoé, Béli, Sirba and Tapoa. Many of these rivers dry up in the dry season (October-June), with the exception of the Mouhoun and Comoé in the south-west which are fed by springs (Bandre *et al*., 1998).

Mean annual rainfall in the Mouhoun and Nakanbé sub-basins varies from approximately 900 mm to less than 600 mm. Over the past 40 years, the precipitation patterns have been of increased dryness, especially between 1970 and 1980. While rainfall increased between 1985 and 1995, the last decades are still marked by the following trends:

- decrease in river flow, decreased availability of groundwater, the drying up of source waters, and degradation of vegetation cover.
- The surface water resources of the basin are made up of stream flows and water in reservoirs.

Table 1 illustrates the distribution of the available surface water resources in the Volta River Basin of Burkina Faso.

Table 2:*Potential Surface Water Resources of the Volta Basin in Burkina FasoPotential Surface Water Resources of the Volta Basin in Burkina Faso*

Sub-basin	**Annual Flow Volume (x 10^9 m^3)**	**Volume in Reservoirs (x 10^9 m^3)**	**Potential in the Basin (x 10^9 m^3)**
Mouhoun (Black Volta	2.64	0.29	2.75
Nakambé (White Volta)	2.44	2.20	3.32
Total	5.08	2.49	6.07

Source: Etat des lieux des ressources en eau et de leur cadre de gestion

The Nankambe River is one of the main tributaries of the Volta River. Its basin covers about 81,932 km2 located in the following four sub-basins:

- Sissili basin 7,559 km²
- Nazion basin 11,370 km²
- Pendjari basin 21,595 km²
- Nouhoa basin 4,050 km²

The first intermittent flows in the Nakambe occur in May. They become permanent flows in July and August at the Wayen station (20,800 km2 watershed) and larger downstream when they reach Bagre (33,120 km2) where there are average values of 65.4 m3/s in July, 145 m3/s in August and 107 m3/s in September. During the three months, 88% of the annual flows at Bagre (29.7m3/s representing 946 Mm3) occur.

The Nazinon and the Sissili Rivers are two of the Nankambe tributaries that collect runoff water from the South-West part of the Mossi plateau. The Pendjari River which forms the border with Benin has three main tributaries: the Doudodo, the Singou and the Kompienga Rivers. These rivers flow during the rainy season (750 -900 mm) and dry up in November. Annual surface water resources from the basin are shown in the following **Table 2**.

Tableau 3 *Potential Surface Water Resources of the Nakambe Basin in Burkina Faso*

Sub-basin	Mean flow (m3/s)	Contribution of the basin (10^6 m^3)
Nakambe	33.4	1,054
Nazinon	6.04	160
Sissili	2.11	67
Pendjari	28.5	899
Nouhao	7.59	239
Total Nakambe Basin in Burkina	77.64	2,444

Existing reservoirs in the Nakambe basin have a total storage capacity of 4.3 billion m3 including the Ziga reservoir. About 27 of the main reservoirs in the basin are frequently monitored and the total volume stored in these reservoirs is estimated at 2.04 billion m3 which represent half of their capacity. Bagre and Kompienga are the largest reservoirs in the Nakambe basin and are used for power generating, irrigation and environmental purposes.

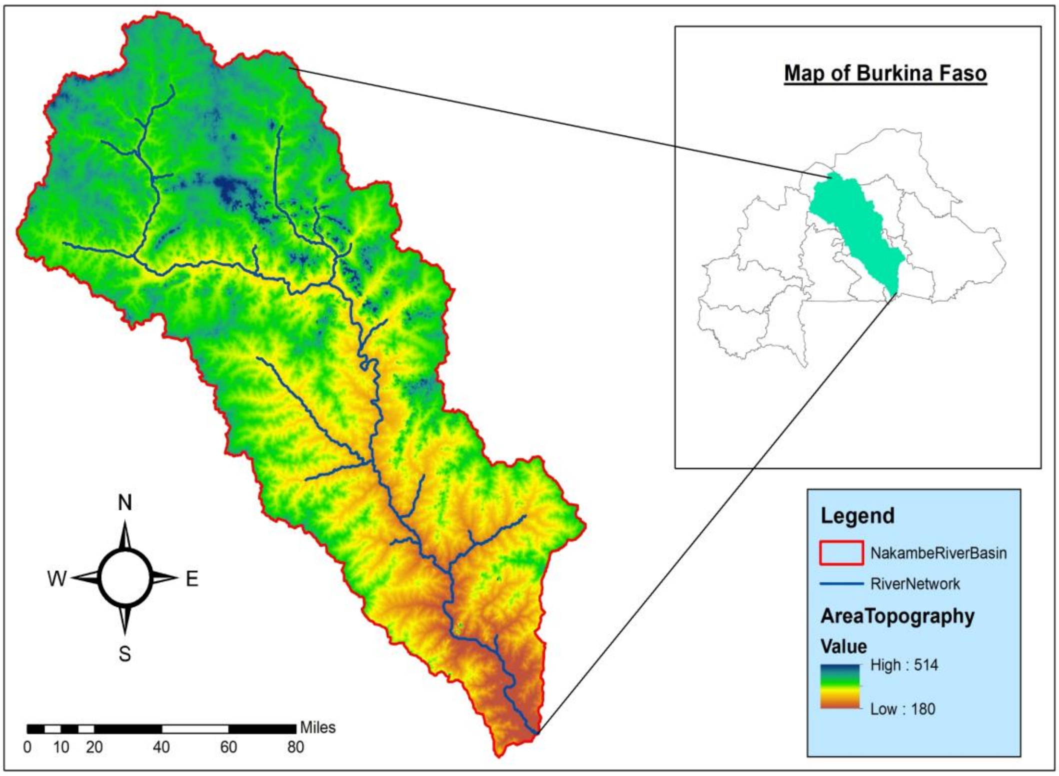


Figure 4: Nakambe River Basin (ARCGIS 10.5)

4 MATERIAL AND METHODS

4.1 Data sources

The daily peak flows data have been obtained from the national agency of Water Ressources (Direction Générale des Ressources en Eau DGRE). These data are covering different period of time of discharge of four (4) hydrometrical station: Bitou, Komptoega, Niaogho, and Yakala, all scattered along a course of the studied basin. An annual maximum time series of discharge have been then established from the primary data (daily peak flows data) through an excel sheet.

4.2 Statistical analysis

The choice of a model is based on statistical considerations, the most common being the visual examination of a graph and the use of a statistical test. The hypotheses of independence, homogeneity and stationarity were respectively verified using the Wald-Wolfowitz, Wil-coxon and Mann-Kendall statistical tests proposed by Hyfran program.

KhronoStat has been used for the tests of Randomness (Autocorrelogram and Rank correlation test) and Tests for breakage detection (Buishand's test, PETTITT's test, LEE and Heghinian's and Hubert's segmentation)

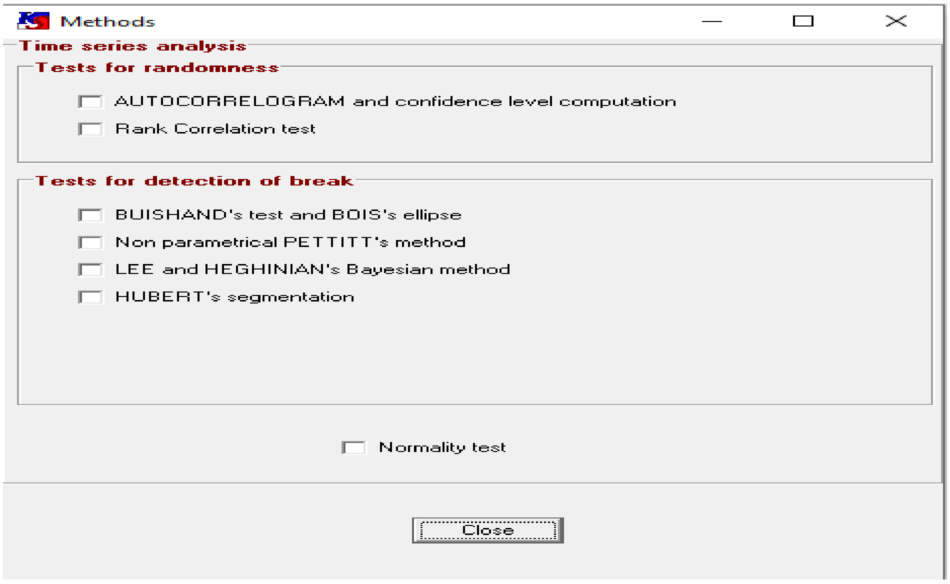


Figure 5: Khronostat interface

4.3 Flood frequency analysis

Hyfran Program has been used for simulation three (3) different probabilistic distribution which are Generalized Extreme Value (Weidbull), Gumbel and Log-Person III distribution based on the method of moments. Through both graphical and criteria analysis, a best distribution of each station has been determined. Hence the best fitting distribution chosen for each station has been used to estimate the discharge for the return period of for 2, 3, 5, 10, 20, 50 and 100 year.

Finally, we propose some policy adaptation and prevention measure to flood risk in the Burkina faso in general and the concerning area study particularly.

5 RESULTS AND DISCUSSIONS.

5.1 Results

5.1.1 Results of Khronostat program

Table 4:Test of Independance (Wald-Wolfowitz)							
		Bagré	**Bitou**	**komptoèga**	**Niaogho**	**Sanogo**	**Yakala**
Hypothesis	H0	observations are independent					
	H1	Observations are dependent (autocorrélation d'ordre 1)					
Results	Statistic value	0.845	0.488	0.542	1.35	1.97	0.273
	P.Value	0.398		0.588	0.178	0.0483	0.785

Conclusion Stuffed Bitou Komptoèga Niaogho Yakala: We can accept H0 at the 5% level of significance. Sanogo: we have to reject H0 at the 5% significance level but accept it at the 1% significance level.

Table 5:Test of Stationarity (Kendall)

Table 5:Test of Stationarity (Kendall)							
		Bagré	**Bitou**	**komptoèga**	**Niaogho**	**Sanogo**	**Yakala**
Hypothesis	H0	No trends observed					
	H1	Trends observed					
Results	Statistic value	0.376	0.553	0.42	0.968	0.206	2.01
	P.Value	0.707	0.58	0.675	0.333	0.837	0.0443

Conclusion Stuffed Bitou, Komptoèga NiaoghoSanogo: We can accept H0 at 5% significance level. Yakala: we must reject H0 at the 5% significance level but accept it at the 1% significance level

Table 6:Test of Homogeniety at annual scale (Wilcoxon)

Table 6 :Test of Homogeniety at annual scale (Wilcoxon)								
		Bagré	**Bitou**	**komptoèga**	**Niaogho**	**Sanogo**	**Yakala**
Hypothesis	H0	The averages of the two sub-samples are equal					
	H1	The averages of the two sub-samples are equal					
Results	Statistic value		0.68	1.37	0.669	N/D	1.83
	P value		0.497	0.171	0.504	N/D	0.0679
	Starting year of 1st group	N/D	1973	1994	1964	2005	1955
	Ending year of 1st group	N/D	1994	1994	1964	1994	1994

Conclusion Bitou Yakala: We can accept H0 at the significance level of 5. We cannot conclude that the averages of the two sub-samples are different.

Niaogho Komptoèga baguette: Divide the sample into two subgroups before applying the Wilcoxon test. Sanogo: Sample size too small to apply test

5.1.2 Results of the Independence Tests

Table 7:Results related to rank correlation test

	Bagre	Bitou	komptoega	Niaogho	Sanogo	Yakala
Statistics values	-0.5636	-0.5527	0.4548	-0.9878	0.2743	-1.8732
Conclusion on h0	accepted	accepted	accepted	accepted	accepted	accepted

Notes: The null hypothesis (randomness of time series) has been accepted at the confidence level of 90%, 95% and 99%. H0 has been only rejected at confidence level of 90%.

5.2 Results of the Homogeneity Tests

Tableau 8:Results on break test

TEST	Investigative work	Bagre	Bitou	komptoega	Niaogho	Sanogo	Yakala
	Break probability	0.3483	0.0934	0.1312	0.0907	-	-
LEE AND HEGHINIAN	Conclusion on H0				accepted	-	-
	Break date	2018	1973	1994	1996	-	-
	Exceedance probability					-	-
PETTITT	Conclusion on H0	accepted	accepted	accepted	accepted	accepted	Accepted
	Break date					-	-
HUBERT	Conclusion on H0					-	-
	Break date						
BUISHAND	Conclusion on H0	rejected	accepted	accepted	accepted	-	-
	Break date					-	-

5.2.1 Results of flood frequency analysis.

Both graphical comparison and specific criteria (BIC and AIC) comparison have been done to consolidate the results.

The probability distribution which has the lower BIC and AIC is the one fitting better the data series (section 2.3.4). Hence, Log-Person Type 3 is fitting better the discharge series for Bitou and Yakala stations, and should be use prediction for different period return. For Niaogho and Komptoega stations, the GEV (Weidbull) is fitting better the peak flow data series

5.2.1.1 Yakala Station

Table 9: Best distribution of Yakala Station based on criteria comparison

Sample size	38 years					
Model distribution	Nb param	XT	P(Mi)	P(Mi/x)	BIC	AIC
Log-Person Type 3 (methods of moment)	3	415.492	33.33	57.77	461.668	456.755
Weidbull (methods of moment)	2	472..626	33.33	41.57	462.326	459.051
Gumbel (methods of moment)	2	534.577	33.33	0.66	470.598	467.323

P(Mi) : A priori probability P(Mi/x) : A posteriority probability; BIC : Bayesian Information Criteria; AIC: Akaike Information Criteria;

Figure 6:Best distribution of Yakala Station based on graphical comparison

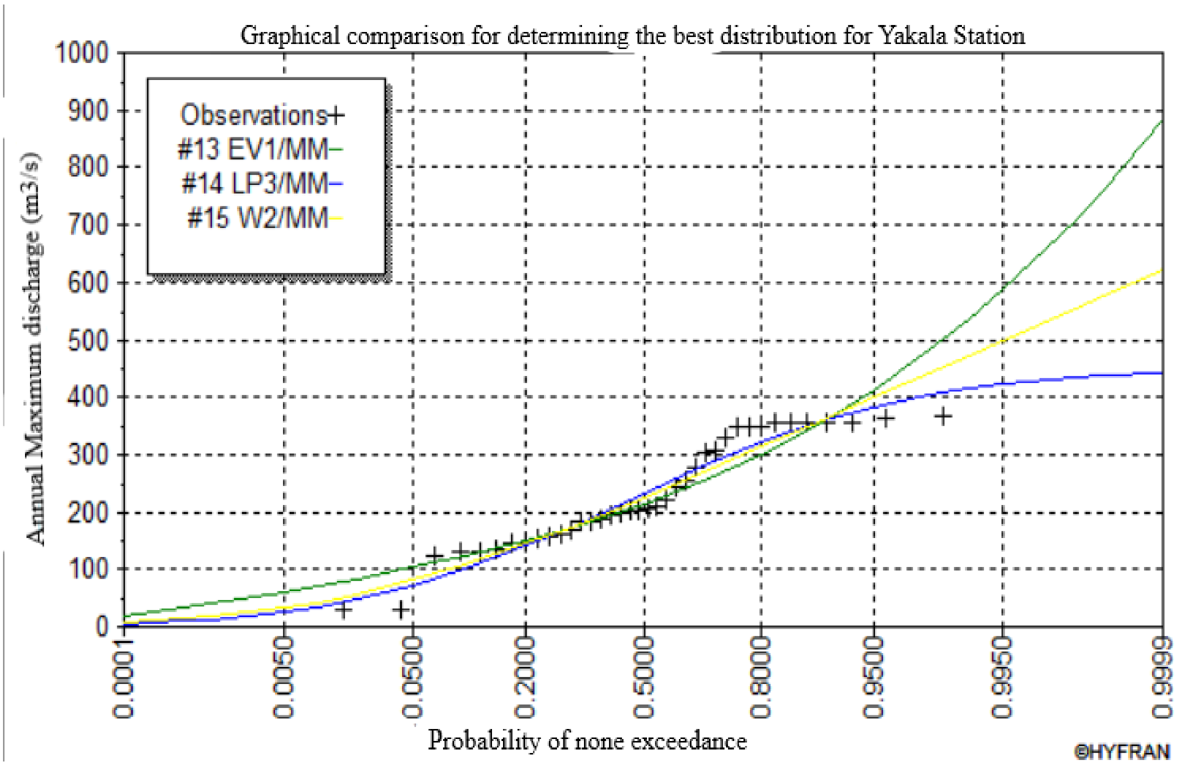


Table 3:Log-Pearson distribution for return period estimation (Yakala)

T	q	XT	Standard deviation	Interval of Confidence
2	0.5000	232	19.7	194-271
3	0.6667	279	19.7	241-318
5	0.8000	321	18.9	284-359
10	0.9000	359	17.2	325-393
20	0.9500	384	17.8	349-418
50	0.9800	405	22.3	361-448
100	0.9900	415	26.7	363-468

Parameters estimated	
alpha	-5.99652
lamda	1.97677
m	2.64213
Level of confidence	95%

5.2.1.2 Bitou Station

Table 11: Best distribution of Bitou Station based on criteria comparison

Sample size	38 years					
Model distribution	Nb param	XT	P(Mi)	P(Mi/x)	BIC	AIC
Log-Person Type 3 (methods of moment)	3	346.783	33.33	68.69	481.534	476.321
Weidbull (methods of moment)	2	386.605	33.33	31.31	483.105	479.630
Gumbel (methods of moment)	2	448.808	33.33	0.00	511.562	508.087

Parameters estimated	
alpha	-0.4214
lamda	42.3904
m	2.55294
Level of confidence	95%

Figure 7: Best distribution of Bitou Station based on graphical comparison

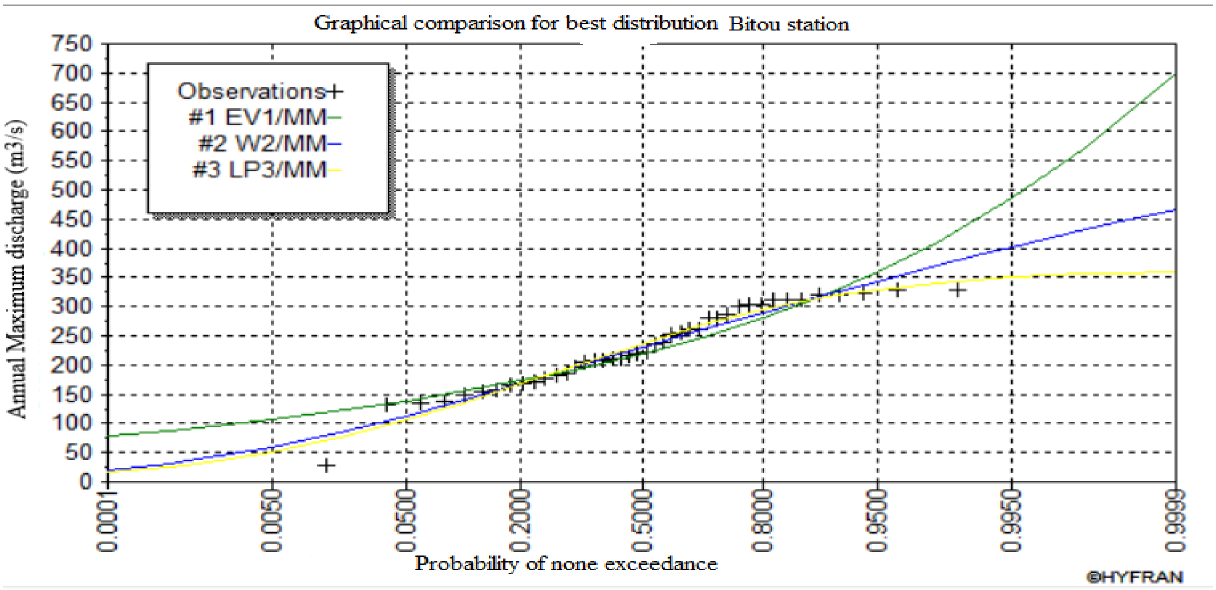
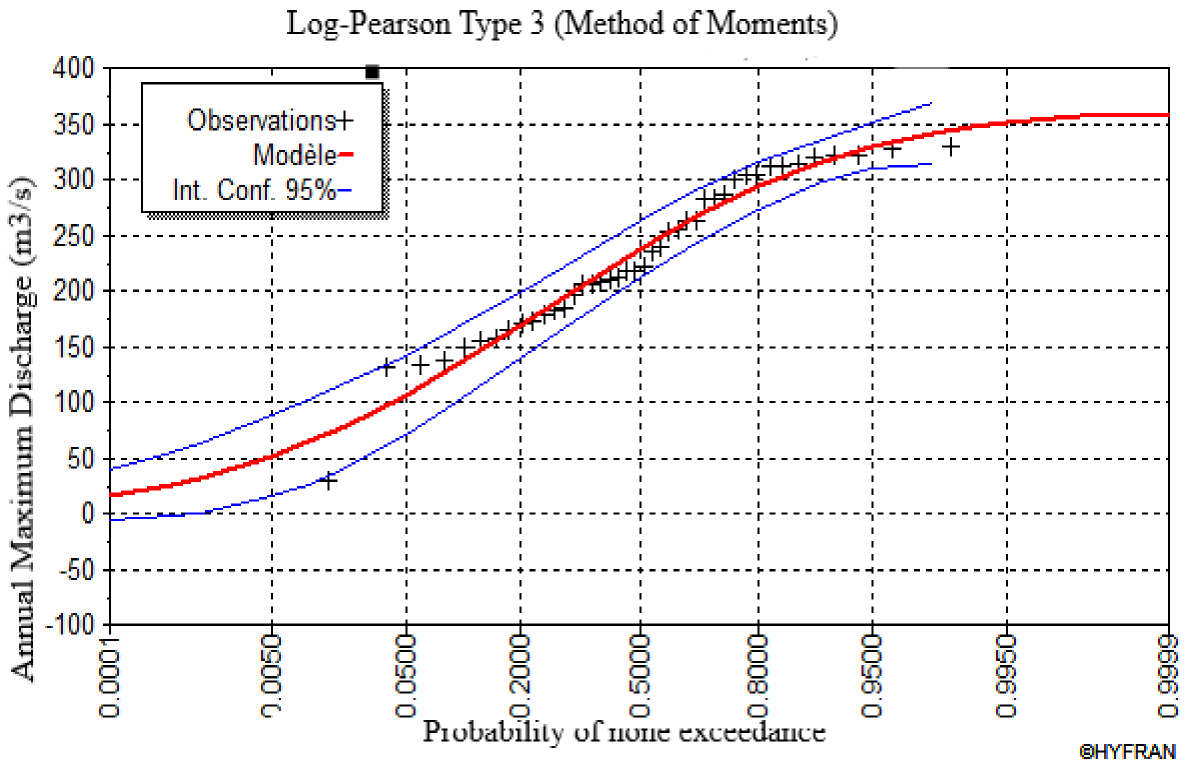


Table 12: Log-Pearson distribution for return period estimation (Bitou)

T	q	XT	Standard deviation	Interval of Confidence
2	0.5000	237	13.3	211-263
3	0.6667	268	12.3	244-292
5	0.8000	294	10.9	273-316
10	0.9000	316	9.54	298-335
20	0.9500	330	10.7	309-351
50	0.9800	341	14.4	313-370
100	0.9900	347	17.5	N/D

Parameters estimated	
alpha	-0.4214
lamda	42.3904
m	2.55294
Level of confidence	95%

Figure 8: Probability distribution of discharge data (Bitou)



5.2.1.3 Komptoega

Table 13: Best distribution of Komptoega Station based on criteria comparison

Sample size	19 years					
Model distribution	Nb param	XT	P(Mi)	P(Mi/x)	BIC	AIC
Weidbull (methods of moment)	2	277.323	33.33	99.83	220.939	219.050
Gumbel (methods of moment)	2	318.179	33.33	0.17	233.699	231.810
Log-Person Type 3 (methods of moment)	3	0.000	33.33	N/D	N/D	N/D

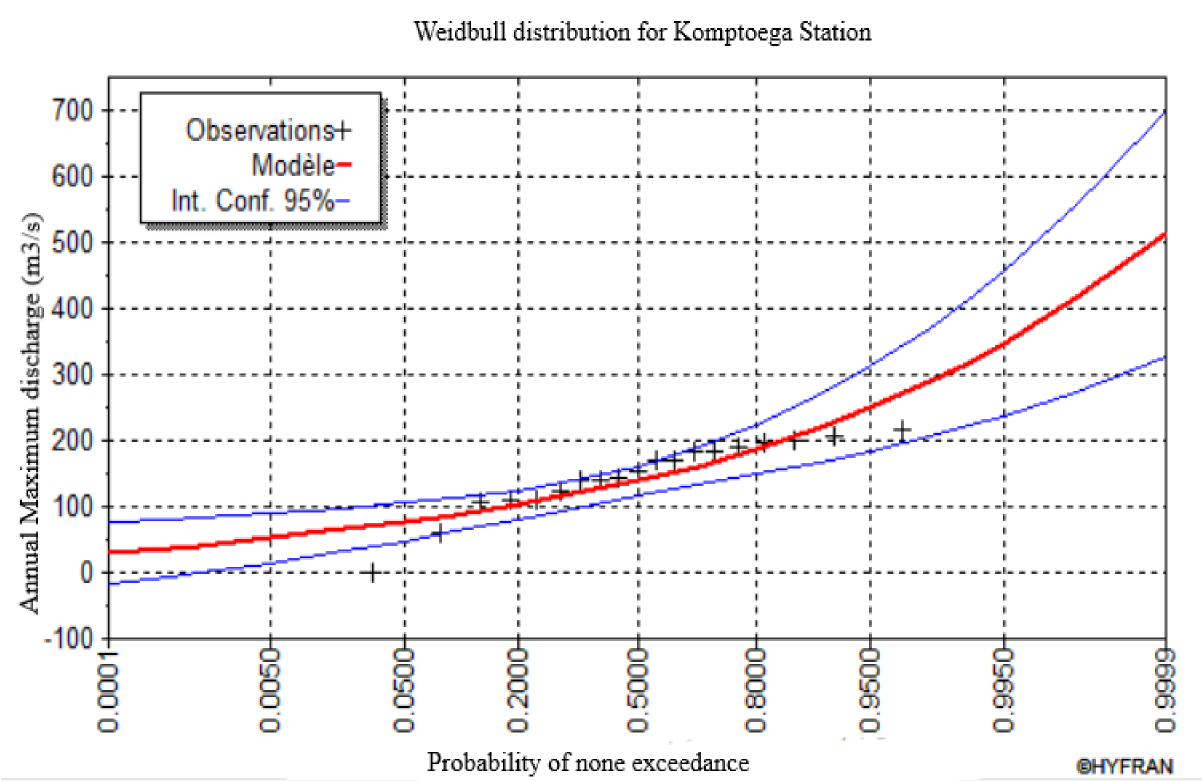
Table 14: Weidbull distribution for return period estimation (Komptoega)

T	q	XT	Standard deviation	Interval of Confidence
2	0.5000	146	14.8	224-331
3	0.6667	171	11.4	218-271
5	0.8000	194	9.61	208-271
10	0.9000	219	11.6	197-242
20	0.9500	240	16.0	176-213
50	0.9800	262	22.5	148-193
100	0.9900	277	27.4	117-175

Parameters estimated	
alpha	165.445
c	2.95654
Level of confidence	95%

Where q=probability of none exceedance

Figure 9: Probability distribution of discharge data (Komptoega)



5.2.1.4 Niaogho

Table 15: Best distribution of Niaogho Station based on criteria comparison

Sample size	28 years					
Model distribution	Nb param	XT	P(Mi)	P(Mi/x)	BIC	AIC
Weidbull (methods of moment)	2	437.686	33.33	55.96	335.138	332.474
Gumbel (methods of moment)	2	496.233	33.33	27.48	336.560	333.896
Log-Person Type 3 (methods of moment)	3	424.790	33.33	16.57	337.572	333.576

Figure 10: Best distribution of Niaogo Station based on graphical comparison

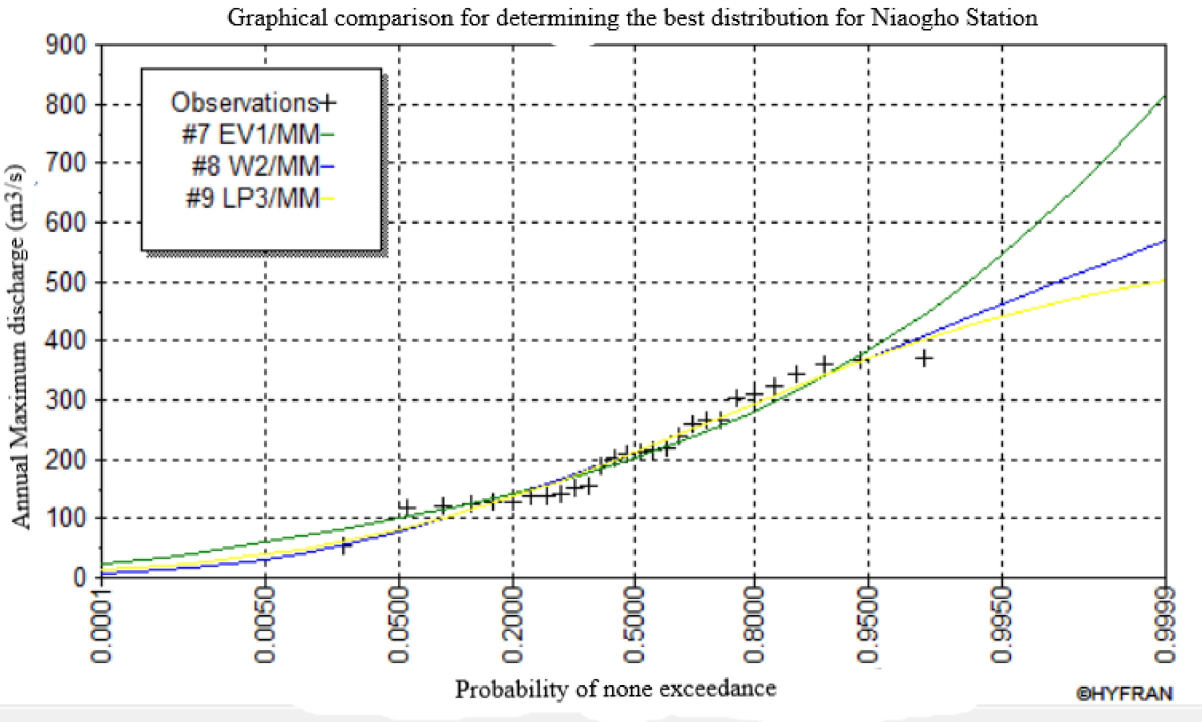
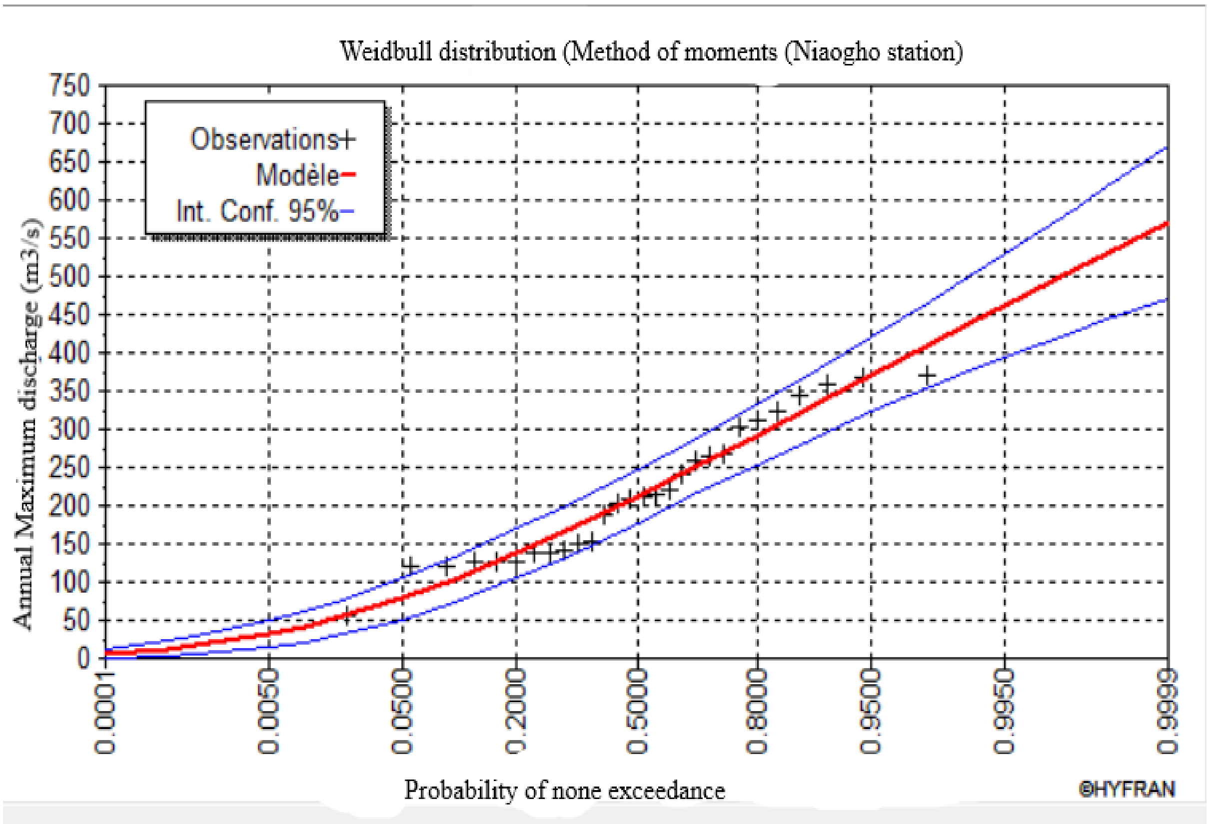


Table 4:Weibull distribution for return period estimation (Niaogho)

T	q	XT	Standard deviation	Interval of Confidence
2	0.5000	438	17.7	177-246
3	0.6667	411	18.4	217-289
5	0.8000	371	19.7	254-331
10	0.9000	336	22.1	292-379
20	0.9500	292	24.8	323-420
50	0.9800	253	28.6	355-467
100	0.9900	212	31.6	376-500

Parameters estimated	
alpha	243.699
c	2.60804
Level of confidence	95%

Figure 11: Probability distribution of discharge data (Niaogho)



5.3 Discussion

The study of the performances of stationarity tests carried out in this third part shows that the methods available are approximately equivalent and generally powerful. In particular, it is difficult to detect a break of small importance (power of the order of 10% for an average failure of 25% of the standard deviation). We have to wait until the amplitude of the rupture becomes of the same order of magnitude as the standard deviation to have a correct probability of detecting breaks (power of the order of 70%).

Comparing conventional tests tends to favor Kendall's tests and the linear regression to detect a trend and those of Buishand and accumulated sums to spot a break. But the performances are however of the same order of magnitude.

We were also able to appreciate the importance of the hypothesis independence of the data. Indeed, for series whose autocorrelation coefficient first order is greater than 0.3, the test results are no longer reliable. However, the parametric methods studied are quite robust with respect to a gap in normality (provided the distribution is not too asymmetrical).

In addition, the stationarity test of the flood occurrence process seems to be suitable for studying the evolution of the frequency of floods. We compared his performance with those of conventional tests applied to series such as "annual number of floods sup-threshold »The results are comparable.

6 ADAPTATIONS and PREVENTION MEASURES

6.1 MEASURE OF ADAPTATION TO CLIMATE CHANGE

It is difficult to separate the effects of climate variability and change from those of anthropogenic factors. However, during the last four decades, extreme weather events (droughts, floods, sandstorms, temperature peaks) have become more frequent and intense and are, therefore, real catalysts for the degradation of the biophysical environment (Ministry of Environment and the Living Environment, 2006). Rainfall and temperature are the two climatic parameters that have the greatest climatic impact on resources and the main sectors of activity because of their evolutionary tendency and especially their interannual and intra-seasonal variability. Floods, waves of heat or dust, drought, rising temperatures, are all extreme events that follow one another and are now part of the daily lives of humans and especially Sahelians. In Ouagadougou, the impacts of climate change are felt a priori in peripheral districts. This is due to the fact that they lack sanitation and sewage and rainwater disposal facilities. Thus these areas are regularly flooded from the first rains. The alternation of floods, heat waves and cold coupled with the late start of the seasons and the drought shows signs that the city of Ouagadougou is being hit hard by the impact of climate change (Ministry of the Environment). Environment and the Living Environment, 2006). While climate change is a global phenomenon, the consequences of climate change vary from one region to another. Hence the need to adapt to the current context. It is therefore imperative that climate change be taken as elements to be included in the strategies, projects and programs of action set in motion in the perspective of communal development. It is in this context that the actions to be favored in the direction of adaptation to the phenomenon of climate change are:

- Sensitization of populations on CC and their implications for the urban economy;
- the production of knowledge to help manage the consequences of CC;
- Solicit the capacity of municipalities to consider CC in development planning;

6.2 MEASURES FOR PREVENTING RISK OF FLOODING

6.2.1 Phases

As with all other natural hazards, flood risk management has traditionally been broken down into three major phases: forecasting, crisis management and prevention. Each of these phases has specific areas and requirements in terms of area considered. Flood risk management falls under the authority of several state services. Their missions are defined by a series of legislative and regulatory texts.

6.2.2 First phase: forecasting and anticipation

Forecasting is the upstream process based on the modeling of phenomena and the regular observation of representative variables. While anticipation makes it possible to prepare the means of answers if the forecast of evolution towards a crisis situation is confirmed. It is at this stage that the weather services intervene to anticipate the meteorological event and the flood warning services for the flood announcement in case of exceeding the warning numbers. Alert messages are sent to the appropriate crisis management authorities.

6.2.3 Second phase: crisis management

Crisis management aims to manage the current event, to ensure the safety of goods and people. This phase is provided by the civil security services whose missions are first to ensure the safety of property and people, emergency relief and evacuation of victims, following the organization of the safeguarding measures and the means of relief, and finally to prevent and assess the risks of civil security.

6.2.4 Third phase: prevention

Prevention draws the consequences of past experiences and makes recommendations to limit the effects of a similar event in the future. - to limit risk-prone areas, taking into account the nature and intensity of the risk involved, and to prohibit any type of construction, work, development or agricultural, forestry or craft exploitation which may be authorized to prescribe the conditions under which they must be made, used or exploited;

- delimit zones that are not directly exposed to risks but where constructions, works, could aggravate risks or provoke new ones and include prohibitions or prescriptions as provided for in {1}.

- Define preventive, protective and safeguarding measures that must be taken by public authorities in the areas mentioned in {1} and {2}, as well as those that may be the responsibility of individuals. This will consist essentially of the establishment of a real awareness of flood risk by sensitizing residents to prevention campaigns and educational actions;

- - define, in the zones mentioned in {1} and {2} the measures relating to the development, the use or the exploitation of the constructions, works, spaces put in culture or planted existing on the date of the plan approval that must be made by the owners, operators or users. It is at this level that the regular cleaning of the drainage works takes place. The town halls through their technical department and the Department of Cleanliness would benefit from emptying the rainwater evacuation works on a regular basis so that as the rainy season approaches, the risk of flooding is reduced.

7 CONCLUSION AND RECOMMENDATIONS.

7.1 Conclusion

This paper aims to highlight discharge variability at yearly scale Nakambe river basin. To reach our objective, we have proceeded through some analysis based on statistical test of randomness (Autocorrelogram and correlation test of Rank) and rupture (Pettitt, Hubert, Buishand and Lee and Heghinian test), while using the Khronostat software at significance level of 95%.

This study provides useful information to climate experts and water stakeholders in understanding the link between climate instability and water availability, thus contributing to the sustainable management of water resources. However, it is important to keep in mind that the analysis presented is only focused on discharge whereas it is not the only key parameter of the climate. It is also important to recognize the limitations of the Khronostat model. This software does not take into account the existence of gaps within the series to be analyzed. In the future, it would be interesting to find a model that is careless of gaps if we know that in Africa it is very common to have incomplete data. This model should be applied to rainfall, temperature and runoff to determinate relationships between the three, highlight causes of high and low flows, frequency, trends). Statistical analysis on probability of occurrence of dry or wet spells to better evaluate possible changes in water resources availability could also be an asset for the considered region.

7.2 Recommendation/Perspectives Study

Following recommendations have been proposed:

- As the hydrology within the river basin and its hydraulic change continuously, it is necessary to update Floodplain maps in order to disseminate the current information.
- Further research should conduct the economic assessment of the expected damage.
- Cost benefit analysis of any flood mitigation measures should be evaluated before its implementation.

- Different flood management measures should be applied in the Volta river basin to protect its water resources in terms of quality including the entire transboundary countries.
- Establishment of a cartography of the area study considering the different return periods for a better decision making in terms of water resources infrastructures building along the basin.
- Conduct a study that will take into account the role of the release of the bagre dam in the floods downstream of the dam.

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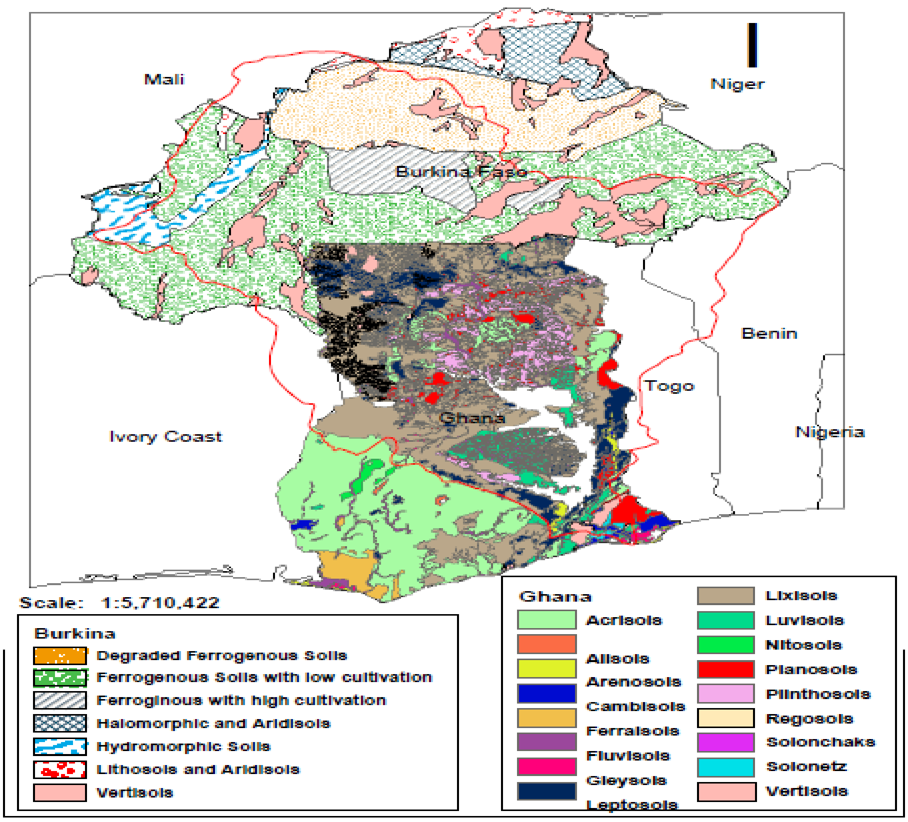
Appendices

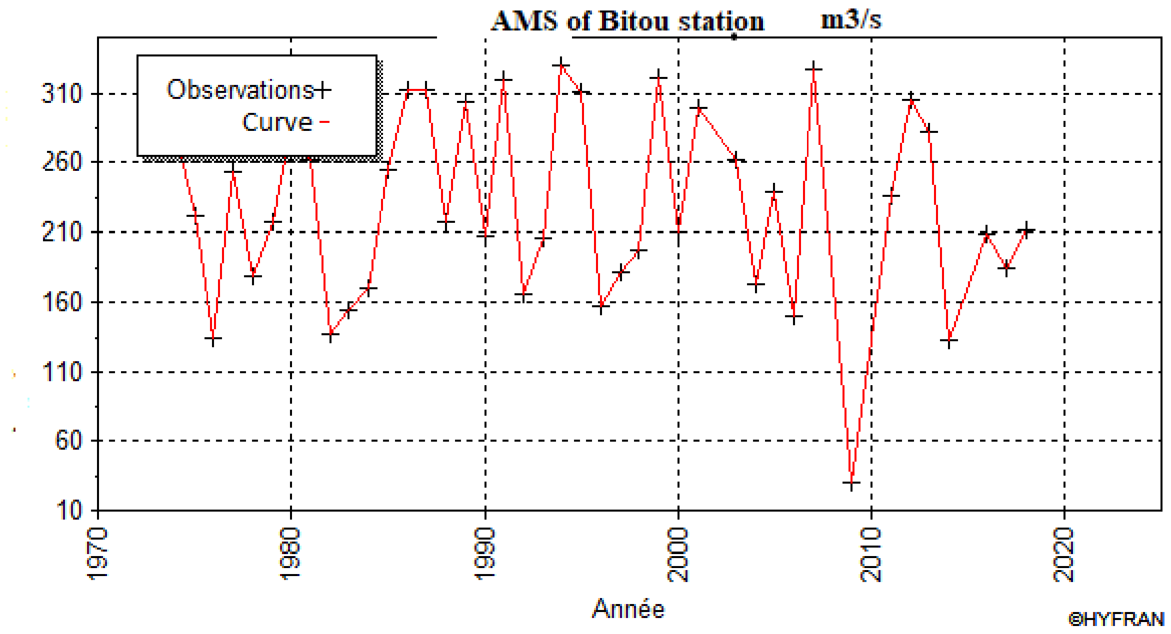
Appendice 1: *Area and length of main tributaries in the Volta River Basin in Ghana*

Sub-basins	Total Area (Km^2)	Rainfall (mm)	Mean Annual Runoff (x10^6m3)	Runoff coefficient (%)	Length (km)
Black Volta	149.015	1023.3-1348.0	7673	8.3	1363.3
White Volta	104.749	929.7-1054.2	9565	10.8	1136.7
Oti	72.778	1150.0-1350.0	11215	14.8	936.7
Lower Main Volta	62.651	1050.0-1500.0	9842	17.0	
Total	400.716	876.3-1555.0			

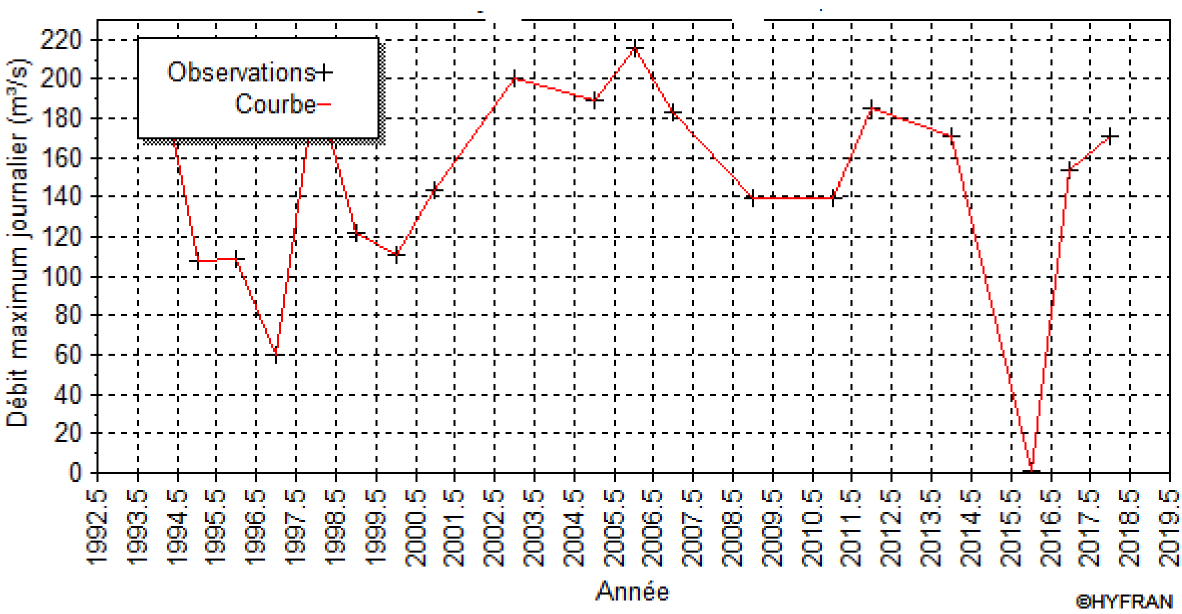


Appendice 2 : Distribution of Soil types in the Volta basin of Ghana and Burkina

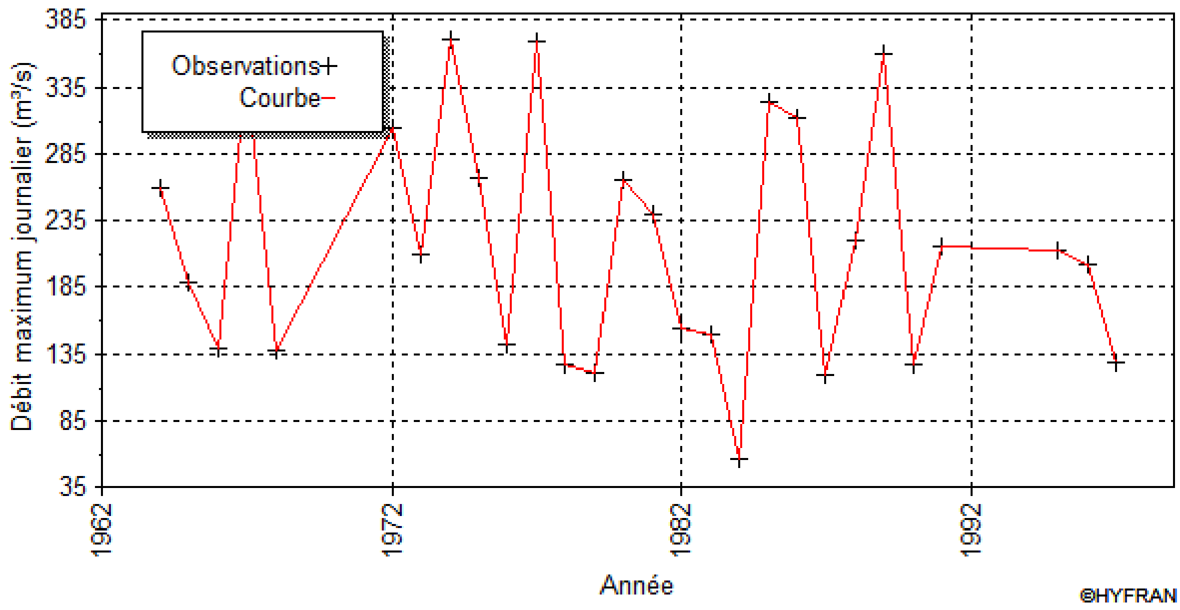
Appendice 3: Annual Maximum Series of Discharge (Bitou Station)



Appendice 4: Annual Maximum Series of Discharge (Komptoega Station)



Appendice 5: Annual Maximum Series of Discharge (Niaogho Station)



Appendice 5: Annual Maximum Series of Discharge (Yakala Station)