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# Characterization of the frequency of hydroclimatic extremes in the lower Ouémé valley

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## ABSTRACT

The study of floods risks requires not only the knowledge of the spatio-temporal variability of precipitation but also and above all, the frequency of occurrence of extreme hydroclimatic events. This study aims to characterize the frequency of extreme hydroclimatic events in the lower Ouémé valley to define their return periods. Daily rainfall data from nine (09) stations were collected and analyzed. They come from the National Meteorological Agency of Benin and cover the period from 1981 to 2019. The methodological approach adopted consisted firstly, in sampling the data to extract the maximum annual values. Then, three (03) hypothesis tests were performed to verify the stationarity, independence, and homogeneity of the data used, namely the modified Mann Kendall, Box Pierce, and Pettitt tests. The choice of the distribution that best fits the data series was done using the Akaike information criterion (AIC) and the Bayes information criterion (BIC) calculated for each of the five (05) extreme value distributions. The lower these values are for a given distribution, the better it fits the data series. The results obtained show that the Gumbel, Lognormal, and GEV distributions are the most suitable for the data series in the study area. The quantiles observed for most of the rainfall stations are contained within the uncertainty band and the highest quantiles are observed with high return periods.

***Keywords:*** frequency analysis, hydroclimatic risks, information criteria, distribution, In land valley of Ouémé

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## I. INTRODUCTION

The global average temperature increased by 0.74°C between 1906 and 2005 with a consequent increase in the variability of extreme hydroclimatic events in several regions (IPCC, 2007). This increase in temperature causes an intensification of the hydrological cycle with an increased recurrence of hydroclimatic extremes. Sub-Saharan Africa is one of the regions most exposed to hydroclimatic risks and must face numerous disasters such as droughts and floods whose frequency and intensity are likely to increase under the effect of global warming (IPCC, 2007; Serdeczny et al. 2017; François and Taabni 2012). Precipitation is one of the most important components of climate (Kouassi et al. 2010), and the greatest impact of future climate change on society will likely come from changes in precipitation. Indeed, disaster losses are on the rise, with serious consequences for the survival and livelihoods of populations, particularly the poor (Ahmad, 2006). In addition to the perverse effects of heavy anthropization on natural ecosystems, risks related to hydroclimatic extremes constitute one of the main natural calamities (Amoussou, 2005; Kodja, 2011) that undermine the development efforts of countries. For example, several extreme floods have occurred over the past 30 years and have caused great economic losses to countries (Kundzewicz 1999; Amoussou et al. 2014; Hounkpè et al. 2015; Ogbonna, Amangabara, and Itulua 2011). The occurrence of floods, therefore, generates many socio-economic impacts (Boko, Adjakpa, and Sedjame 2017; Babilas 2019; M. et al. 2014). It is therefore important to analyze extreme rainfall events for assessment and model development (Aiguo Dai, 2006) to assist in decision making. Furthermore, in West Africa, rainfall is one of the most widely used meteorological parameters for determining climate variability (Kouadio et al, 2003). Its quantification is therefore of paramount importance as it plays an important role in hydrological and climate studies. Scientific research concerning the effects of the occurrence of hydroclimatic extremes on human activities and environmental quality has increased over the last two decades (Bourque 2000; Agenis-Nevers 2006; Decamps 2010; Kodja 2018; Hmidi 2019). Thus, the tropical climate area has been experiencing an increase in studies related to extreme precipitation in particular studies on the frequency analysis of extreme rainfall (Sahani et al., 2012; Habibi et al., 2012; Ozer et al., 2017; Alioun and Camara, 2017). In Benin, particularly in the lower Ouémé valley, several studies related to the characterization of hydroclimatic extremes have been conducted. Kodja (2018) analyzed the indicators of extreme hydroclimatic events in the Ouémé watershed at the Bonou outlet. The results reveal, among others, that daily extreme rainfall events have an occurrence of 2 years, 5 years, 10 years for strong rainfall events; 20 years, for very strong rainfall events; 50 years and more for extremely strong rainfall events in the study area. M'Po et al. (2017) used the ETCCDI indices in addition to the observed and projected REMO model data following the RCP4.5 and RCP8.5 climate scenarios to analyze the trend of extreme rainfall in the Ouémé basin. In most of the stations used by these authors, a significant decrease in days of heavy and very heavy rainfall was observed. Attogouinon et al, (2017), as well as N'Tcha M'Po et al (2017) used the ETCCDI indices to analyze the trend of rainfall extremes in the Ouémé valley. Other authors have also conducted research on hydroclimatic extremes in the lower Ouémé valley (Agbazo et al., 2016; Avahounlin et al., 2017). Admittedly, the methodological approach used in these studies varies from author to author, but none of them used the multiple extreme value distributions approach to deduce the best one for each station in the Lower Ouémé Valley. Also, the need to update the available information and data to assist in decision-making at all socio-economic levels are all reasons that justify the implementation of the present study, which proposes to characterize the frequency of extreme rainfall in the Lower Ouémé Valley to predict the return periods of annual maximum rainfall.

## II. PRESENTATION OF STUDY AREA

Located between latitudes 6°25' and 6°57' North and between longitudes 2°21' and 2°38' East, the lower Ouémé valley is located in the south of Benin in the Ouémé Department. It is a floodplain in the shape of an elongated triangle measuring 90 km from north to south. The lower Ouémé valley has a sub-equatorial climate, characterized by two rainy seasons, a large one from April to July and a small one from September to October. The soils of the lower Ouémé valley are made up of clayey soils, clayey-silt soils, and marl soils with a clay content of essentially 78 to 84%

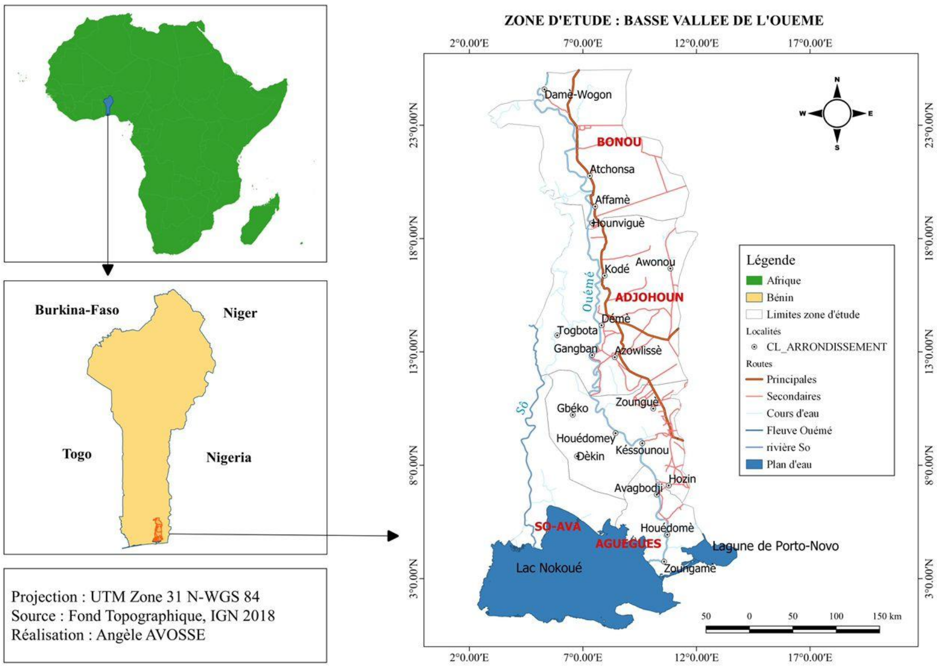

**Figure 1:** Map of the study area

## III. DATA AND METHODS

### 3.1 Data

Daily rainfall data from 9 stations in the Ouémé basin provided by the National Meteorological Agency of Benin (Météo Benin) over the period 1981-2019 were used to generate time series of annual maximum daily rainfall using the R language.

### 3.2 Methodology

One of the basic tools for the analysis of the occurrence of hydroclimatic extremes is the frequency analysis. It is a statistical method of prediction consisting in studying past events, characteristic of a given process (hydrological or other), to define the probabilities of future occurrence (Meylan et al, 2008). The methodological approach adopted to carry out a frequency analysis involves the following steps.

- Sampling

This is a process that consists of extracting the maximum annual values in a series or all values above a given threshold. In the case of this study, the maximum annual value has been extracted to obtain a time series of size equal to the number of years.

- Hypothesis testing

After sampling, the series of maximum values obtained is subjected to hypothesis testing, a necessary condition for a good fit. In practice, changes in the measurement conditions (relocation of stations, replacement of measuring instruments, change of observation times or change in the immediate environment of the measuring instrument) can introduce artificial breaks in the data that do not reflect the real climate variations (Beaulieu et al., 2007). It is therefore essential to verify that the data collected are stationary (statistical characteristics do not vary over time), independent (no autocorrelation between observations), and homogeneous (come from the same distribution). Thus, to verify these three hypotheses, the modified Mann Kendall, Box-Pierce, and Pettitt tests (Aziz, 2003; Souanef, 2015) were respectively used before proceeding to the choice of the distributions to which the series of maximum values are fitted.

- Choice of the extreme value distribution

In the literature, the series of hydroclimatic extremes can be fitted using several extreme value distributions : Exponential, Gamma, Lognormal, Frechet, Pareto, Weibul, Gumbel, Pearson etc. Finding the statistical model that best fits the series of maximum values of the variable under study is therefore crucial for the success of the frequency analysis. Several studies have shown the dominance of Gumbel's distribution (Ague and Afouda, 2015). A World Meteorological Organization (WMO) analysis of 55 agencies in 28 countries reveals that 52% of the agencies use the Generalized Extreme Value (GEV) distribution as their primary reference. This distribution admits as special cases the Gumbel, Fréchet and Weibull distributions, 31% use either a Pearson III distribution or a Log Pearson III distribution, or a Pearson type III distribution (Brahim et al., 2013). There are several criteria including the information criteria and the graphical criteria (Aziz, 2011), for selecting the appropriate distribution for a set of maximum values. Information criteria are the most used (Aziz, 2011; Lawin et al., 2000) and were considered in this study to select distributions that best fit the annual maximal value series. It includes the Akaike Information Criteria (AIC) proposed by Akaike (1974) and defined by:

AIC=-2log(L)+2k

According to this criterion, the deviance of the model (-2log(L)) is penalized by 2 times the number of parameters k. The AIC represents a compromise between the bias which decreases with the number of parameters and the parsimony (the need to describe the data with the smallest number of parameters possible). The Bayes Information Criterion (BIC) proposed by Schwarz (1978) is defined by:

BIC=-2log(L)-klog(n)

In both equations (AIC and BIC), L is the likelihood, K is the number of parameters of the distribution and n is the sample size. After the determination of the two parameters AIC and BIC, the choice of the model or the distribution that best fits the series of extreme values was made. Table 1 presents the distributions used in this study and their density function.

**Table 1:** Statistical distributions, their probability density functions and the parameters.

| **Distribution** | **Density function, f(x)** | **Parameters** |
|---|---|---|
| Gumbel | $(x) = \frac{1}{\alpha} \exp\,[-\frac{x-u}{\alpha} \exp\,(\frac{x-u}{\alpha})]$ | $u;\ \alpha$ |
| Lognormal | $f(x) = \frac{1}{x\sigma\sqrt{2\pi}} exp[-\frac{(\ln(x)-\mu)^2}{2\sigma^2}]$ | $\mu;\ \sigma$ |

| | | |
|---|---|---|
| Weibull | $f(x) = \frac{c}{\alpha}(\frac{x}{\alpha})^{c-1} exp[-(\frac{x}{\alpha})^c]$ | $c;\ \alpha$ |
| Gamma | $f(x) = \frac{\mu^\alpha}{\Gamma(\alpha)} x^{x\alpha-1} exp^{-\mu x}$ | $\mu;\ \alpha$ |
| GEV | $f(x) = exp\left(-\left[1 + k\frac{x-\mu}{\sigma}\right]^{-1/k}\right),\ k \neq 0$<br>$f(x) = exp\left(-exp\left(-\left[\frac{x-\mu}{\sigma}\right]\right)\right), k = 0$ | $\mu;\ \sigma; k$ |

## IV. RESULTS

### 4.1 Hypothesis test

The modified Mann Kendall test applied to the data series shows that the rainfall data used for this study are stationary at the 5% significance level for all stations except for the Bohicon station. Box-Pierce and Pettitt tests (Aziz, 2003; Souanef, 2015) performed on the maximum rainfall series reveal that the data for all stations except Bohicon are homogeneous and independent at the 5% significance level. The results from the different statistical tests applied to the data series are indicated in Table 2.

Table 2: Results of statistical tests applied to maximum rainfall for the different stations

| Stations | Stationarity test | | Independence test | | Homogeneity test | |
|---|---|---|---|---|---|---|
| | U | P | K | P | W | P |
| | Rainfall stations | | | | | |
| Adjohoun | -0.07 | 0.94 | 1.45 | 0.22 | 142 | 0.27 |
| Bohicon | 1.28 | 0.03 | 0.02 | 0.87 | 156 | 0.18 |
| Bonou | -0.16 | 0.88 | 1.02 | 0.3 | 211 | 0.3 |
| Cotonou | -0.13 | 0.89 | 0.16 | 0.687 | 78 | 1.09 |
| Ketou | 0.05 | 0.96 | 0.24 | 0.587 | 72 | 1.19 |
| Ouando | 0.25 | 0.80 | 0.199 | 0.655 | 72 | 1.19 |
| Porto novo | 0.90 | 0.37 | 1.2 | 0.26 | 90 | 0.89 |
| Sakété | 0.21 | 0.84 | 0.067 | 0.79 | 142 | 0.27 |
| Zagnanado | 1.40 | 0.16 | 0.03 | 0.85 | 156 | 0.18 |

### 4.2 Best distribution identification

Table 3 shows the AIC and BIC comparison criteria for the five probability distributions considered. The lower the AIC and BIC of a model, the better the model fits the extreme value series. The Gumbel distribution is the one that best fits the maximum annual rainfall of the stations of Adjohoun, Ouando, Porto-Novo and Zagnanado according to the BIC and AIC criteria, while those of Bohicon and Bonou follow the GEV distribution. The Cotonou and Ketou stations are best fitted with the Lognormal distribution.

Table 3: AIC and BIC comparison criteria for the five probability distributions used on the data series for the different stations

| **Stations** | **Gumbel** | | **Weibul** | | **Lognormale** | | **GEV** | | **Gamma** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | AIC | BIC | AIC | BIC | AIC | BIC | AIC | BIC | AIC | BIC |
| Adjohoun | **361.9** | **365.2** | 369.3 | 372.6 | 362.8 | 367.1 | 363.79 | 368.79 | 362.6 | 367.9 |
| Bohicon | 296.6 | 299.9 | 356.4 | 359.6 | 354.7 | 358.1 | **292.22** | **297.21** | 354.1 | 357.4 |
| Bonou | 303.2 | 306.6 | 354.2 | 357.5 | 341.9 | 345.2 | **300.5** | **305.5** | 344.3 | 347.6 |
| Cotonou | 379.3 | 382.6 | 380.8 | 384.1 | **378.6** | **381.9** | 380.1 | 385.1 | 378 | 381.3 |
| Ketou | 340.7 | 344.1 | 347.3 | 350.6 | **340.2** | **343.6** | 342.3 | 347.3 | 340.8 | 344.1 |
| Ouando | **300.5** | **305.5** | 378.6 | 381.9 | 367.8 | 371.1 | 303.6 | 306.9 | 370.1 | 373.4 |
| Porto-novo | **373.1** | **376.4** | 377.7 | 381 | 375.6 | 378.9 | 1204.6 | 1209.6 | 376.4 | 378.8 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sakété | 343.3 | 346.6 | 345.7 | 349 | **342.6** | **345.9** | 344.4 | 349.4 | 342.6 | 345.9 |
| Zagnanado | **300.1** | **303.5** | 351 | 354.3 | 341 | 344.3 | 302.5 | 306.1 | 342.9 | 346.2 |

Figure 2 shows the distribution curves of the empirical rainfall series and those obtained with the theoretical distributions for each station. The selected distributions fit the data series curves rather well for each of the stations. There are however some dissimilarities between the empirical and the model probability distribution of some stations.

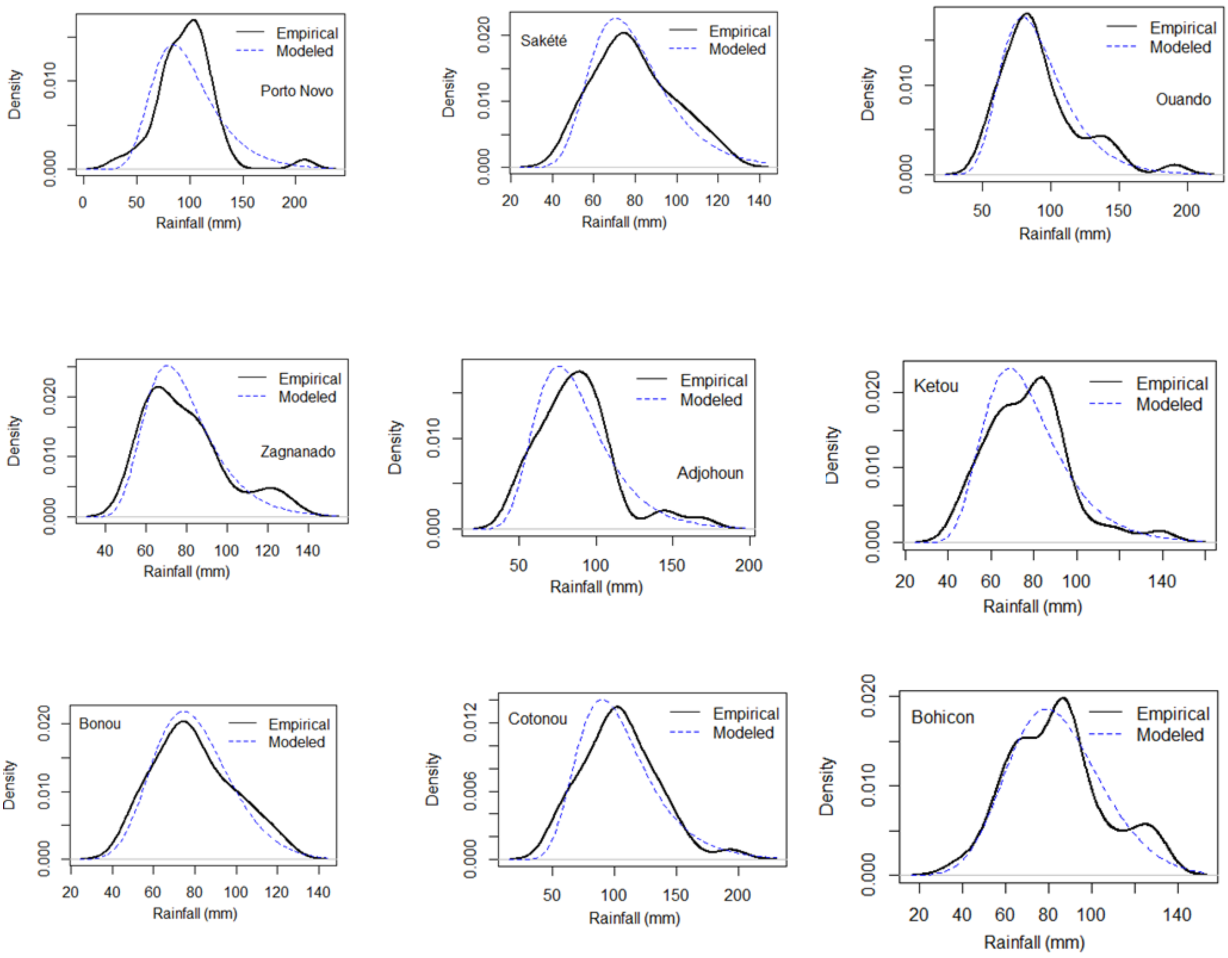

**Figure 2:** Graphical fitting of the probability distributions applied to the data series of the different stations

### 4.3 **Quantiles estimation**

Figure 3 shows the estimated quantiles for different return periods (2, 5, 10, 20, 50, 100 and 200 years, etc.). Confidence intervals are also provided to evaluate the uncertainty associated with the estimates. It is noted that the observed quantiles for most of the rainfall stations are within the uncertainty band. The highest quantiles are observed with high return periods as well. For the Adjohoun station, for example, rainfall with a return period of 5 years is of the order of 103 mm. These results are like those obtained by Agué and Afouda in 2015. The same applies for the Kétou station.

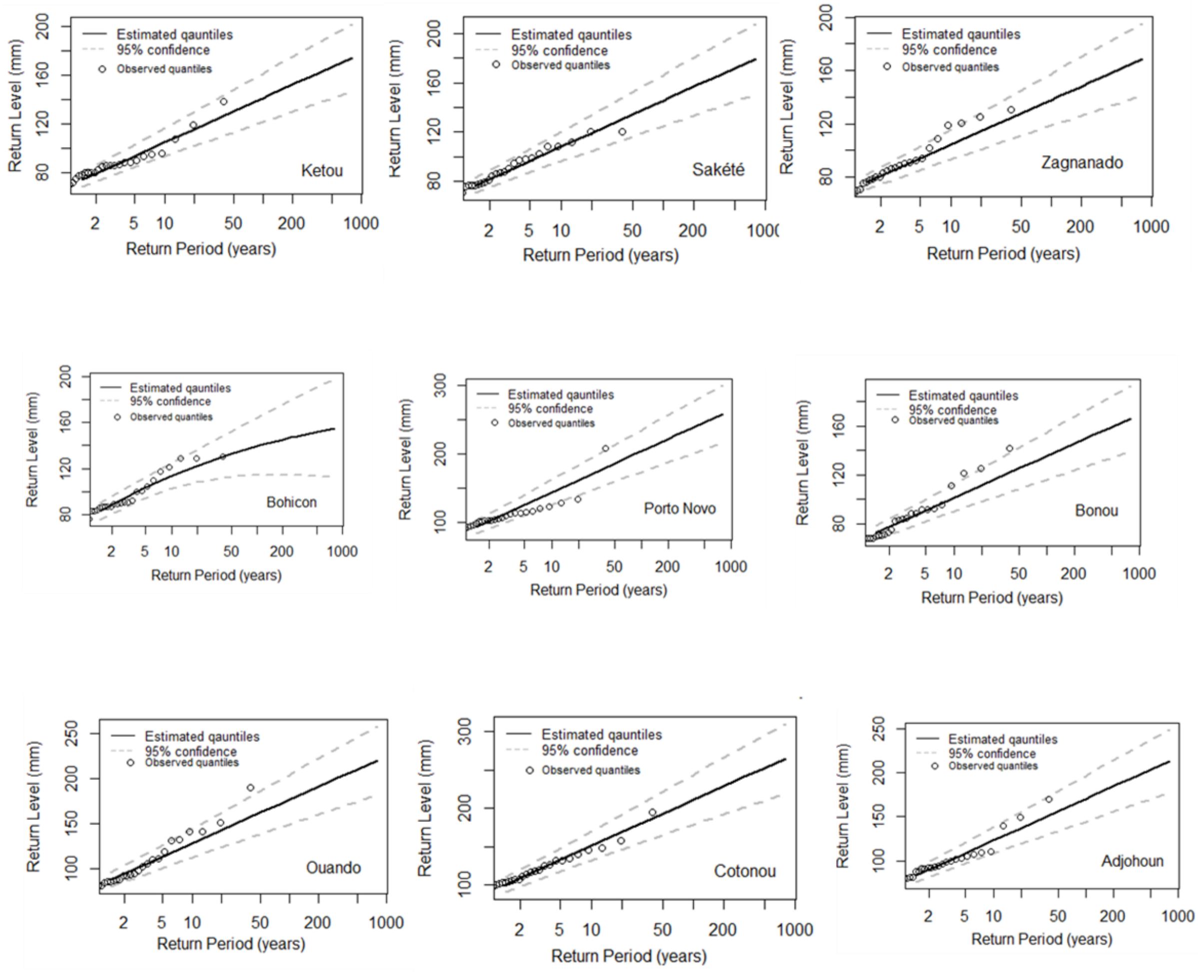

Figure 3: Estimated Return Period Quantiles

## V. DISCUSSION

The various results from this study corroborate those obtained by several other authors. Indeed, according to Ague and Afouda (2015), the evolution of the estimated return quantiles is proportional to that of the return periods as observed in our study. Moreover, according to these same authors, the distributions that fit the different stations in the two (02) studies are the same with a predominance of Gumbel and lognormal distributions. For example, at Adjohoun station, the Gumbel distribution is the best and for a return period of 50 years the estimated rainfall quantile is around 150 mm similarly to Ague and Afouda, (2015). Koungbanane et al (2020), in their study of the Oti watershed in Togo, used GEV distributions with the maximum likelihood method to characterize the frequency of maximum daily rainfall and flood flows. Several other studies on frequency analysis in the sub-region use the same distributions. GEV distribution is therefore among the most suitable for frequency analysis in West Africa.

## VI. CONCLUSION

The present study consisted of a frequency analysis of maximum rainfall in the Lower Ouémé Valley. To do this, we used data from nine rainfall stations in and around the study area over 39 years. The results of this analysis show that, overall, the statistical tests performed on the data series are conclusive. Despite the predominance of Gumbel's distributions, the other distributions are also able to estimate the rainfall quantiles for the different return periods considered. The return periods vary from 2, 5, 10, 50 to 1000 years for the estimated quantiles, but with the confidence interval increasing as the number of years increases. These rainfall values estimated for different return periods will be very useful for a better knowledge and management of hydroclimatic risks in the Lower Ouémé Valley.

## REFERENCES

[1]. Agbazo, M. et al. 2016. “Estimación de Las Curvas IDF de Extrema Precipitación Por Escala Simple En El Valle Oueme, Al Norte

de La República de Benín (Africa Occidental).” *Earth Sciences Research Journal* 20(1): D1–7.
[2]. Ague, Alain Ibikunlé, Abel Afouda, and Flavien Lanhoussi. 2014. “Revue Scientifique et Technique. LJEE N°24&25 Juin-Déc 2014.” : 1–8.
[3]. Amoussou, Ernest et al. 2015. “Péjoration Climatique et Dynamique Hydroécologique Dans Le Bassin-Versant Du Fleuve Ouémé à Bonou Au Bénin.” *Conférence internationale sur l’hydrologie des grands bassins fluviaux de l’Afrique*:
[4]. Amoussou1, Ernest, Lucien Marc Oyede2, and et Michel Boko. 2005. “Variabilité Pluvio-Hydrologique et Production Agricole Dans Le Bassin Du Couffo Au Bénin (Afrique de l’Ouest).” *XIXe Colloque de l’Association Internationale de Climatologie*.
[5]. Attogouinon, André, Agnidé E. Lawin, Yèkambèssoun N.Tcha M’Po, and Rita Houngue. 2017. “Extreme Precipitation Indices Trend Assessment over the Upper Oueme River Valley-(Benin).” *Hydrology* 4(3): 1–24.
[6]. Avahounlin, Ringo F et al. 2013. “Analyse Fréquentielle Des Séries de Pluies et Débits Maximaux de L ’ Ouémé et Estimation Des Débits de Pointe.” *European Journal of Scientific Research* 107(3): 355–69. http://www.europeanjournalofscientificresearch.com.
[7]. Aziz, Hebal, and Boualem Remini. 2011. “Choix Du Modèle Fréquentiel Le plus Adéquat à l’estimation Des Valeurs Extrêmes de Crues (Cas Du Nord de L’algérie).” *Canadian Journal of Civil Engineering* 38(8): 881–92.
[8]. Beaulieu, C., T.B.M.J. Ouarda, and O. Seidou. 2007. “A Review of Homogenization Techniques for Climate Data and Their Applicability to Precipitation Series.” *Hydrological Sciences Journal* 52: 18–37.
[9]. Boko, M, R A Sedjame, Laboratoire Pierre, and Pagney Climat. 2017. “Les Facteurs Naturels Et Le Forçage Anthropique Des Inondations En Zone Sahelienne Dans Le Bassin Du Niger Au Benin ( Afrique De L ’ Ouest ).” *journal of water and environment science* 1: 77–83.
[10]. Bourque, Alain. 2010. “Les Changements Climatiques et Leurs Impacts.” *Vertigo- la revue électronique en sciences de l ’ environnement [EN LIGNE]* 1: 1–17. http://journals.openedition.org/vertigo/4042.
[11]. Dai, Aiguo. 2006. “Precipitation Characteristics in Eighteen Coupled Climate Models.” *Journal of Climate* 19(18): 4605–30.
[12]. Décamps H., Mathieu N. 2005. “« Événements Extrêmes : Retours d’expérience ».” *Natures Sciences Société* 13: 369–70.
[13]. Eau, Terre Master et al. 2013. “Mémoire de Fin d’études Intitulé :”
[14]. François, Alain, and Mohamed Taabni. 2012. “L ’ Afrique Face Aux Changements Climatiques Introduction.” *Les Cahiers d ’ Outre-Mer* 260: 459–62.
[15]. GIEC. 2007. “Le Rapport Du GIEC (2007) Sur Le Réchauffement Climatique.” : 2007.
[16]. Henry, Décamps. 2011. 8 La Météorologie *Événements Climatiques Extrêmes : Réduire Les Vulnérabilités Des Systèmes Écologiques et Sociaux.*
[17]. Hounkpè, Jean, Bernd Diekkrüger, and Abel A Afouda. 2019. “Land Use Change Increases Flood Hazard : A Multi ‑ Modelling Approach to Assess Change in Flood Characteristics Driven by Socio ‑ Economic Land Use Change Scenarios.” *Natural Hazards* (0123456789). https://doi.org/10.1007/s11069-018-3557-8.
[18]. Hounvo, S. Ferdinand et al. 2019. “Analyse Statistique Des Pluies Journalières Extrêmes à Partir d’un Seuil Dans Le Bénin Subéquatorial.” *Journal de Physique de la SOAPHYS* 1(1): C19A13-1-C19A13-6.
[19]. Kodja, Domiho Japhet. 2018. “Indicateurs Des Évènements Hydroclimatiques Extrêmes Dans Le Bassin Versant de l ’ Ouémé à l ’ Exutoire de Bonou En Afrique de l ’ Ouest.” *Géographie. Université Montpellier; Université d’Abomey-Calavi (Bénin),*.
[20]. Kouadio, Yves. 2003. “Etude de La Prédictibilité de La Pluviométrie En Côte d ’ Ivoire Durant La Période de Juillet à Septembre.” : 1–6.
[21]. Kouassi, Michel. 2010. “Analyse Des Impacts Des Changements Climatiques Sur Les Normes Hydrologiques En Afrique de l ’ Ouest : Cas Du District d ’ Abidjan ( Sud de La Côte d ’ Ivoire ).” *Revue des sciences de l’Eau* 32(3): 207–20.
[22]. Kundzewicz, Zbigniew W., and Kuniyoshi Takeuchi. 1999. “Flood Protection and Management: Quo Vadimus?” *Hydrological Sciences Journal* 44(3): 417–32.
[23]. Lalèyè, Philippe et al. 2006. “Studies on the Biology of Two Species of Catfish Synodontis Schall and Synodontis Nigrita

(Ostariophysi: Mochokidae) from the Ouémé River, Bénin." *Belgian Journal of Zoology* 136(2): 193–201.

[24]. G. Mahe, Variabilité pluie-débit en Afrique de l'Ouest et Centrale au 20ème siècle : changements hydro-climatiques, occupation du sol et modélisation hydrologique. Mémoire d'HDR, Université de Montpellier II, 2006, 160 p.

[25]. Meylan, P, AC Favre, and A Musy. 2008. *Hydrologie Fréquentielle: Une Science Prédictive*.

[26]. Montchowui, P, Tobada, A Chikou, and P Laleye. 2008. "Caractéristiques et Impact de La Pêche Artisanale Sur L\'exploitation de Labeo Senegalensis (Valenciennes, 1842) Dans La Basse Vallée Du Fleuve Ouémé Au Bénin."

[27]. N'Tcha M'Po, Yèkambèssoun et al. 2017. "Decreasing Past and Mid-Century Rainfall Indices over the Ouémé River Basin, Benin (West Africa)." *Climate* 5(3): 74.

[28]. Ogbonna, D N, G T Amangabara, and P A Itulua. 2011. "Study of the Nature of Urban Flood in Benin City, Edo State; Nigeria." *Global Journal of Pure and Applied Sciences* 17(1): 7–21. www.globaljournalseries.com,.

[29]. Ozer, P., Y. C. Hountondji, and O. Laminou Manzo. 2009. "Evolution Des Caractéristiques Pluviométriques Dans l'est Du Niger de 1940 à 2007." *Geo-Eco-Trop* 33: 11–30.

[30]. Philippe, Félix, Andrew Sturman, and Hervé Quenol. 2013. "Variabilité Spatiale Des Températures Dans Le Contexte Du Changement Climatique a l'échelle Du Vignoble de Marlborough (Nouvelle-Zélande)." *Climatologie* 10: 123–45.

[31]. Sahani, Muhindo et al. 2012. "Evolution Des Caractéristiques Pluviométriques Dans La Zone Urbaine de Butembo (RDC) de 1957 à 2010." *Geo-Eco-Trop : Revue Internationale de Géologie, de Géographie et d'Ecologie Tropicales* 36(1): 121–36. http://hdl.handle.net/2268/156133.

[32]. Serdeczny, Olivia et al. 2016. "Climate Change Impacts in Sub-Saharan Africa : From Physical Changes to Their Social Repercussions." *Reg Environ Change* 17.

[33]. Souanef, Nassima. 2015. "Analyse Fréquentielle Des Débits Max de Crues de l'Oued Abiod." *Mémoire présenté en vue de l'obtention Du diplôme de Magister en : Hydraulique*.

[34]. R. Ogouwale, Changements climatiques et modélisation hydroclimatique dans le bassin versant de l'okpara (Afrique de l'Ouest). *XXVIIIe Colloque de l'Association Internationale de Climatologie, Liège,* 2015, 6p.

[35]. R. Ogouwale, Changements climatiques, dynamique des états de surface et prospectives sur les ressources en eau dans le bassin versant de l'Okpara à l'exutoire de Kaboua. *Thèse de Doctorat Unique de l'Université d'Abomey-Calavi*, 2013, 203 p.

[36]. P. Ouassa, Variabilité hydro-pluviométrique et production agricole dans la Commune de Toucountouna, *Mémoire de maîtrise. DGAT/FLASH/UAC,* 2014, 89p.

[37]. D. A. Tidjani, A. Abdou, P. Ozer, Perceptions de la variabilité climatique et stratégies d'adaptation dans le système oasien de Gouré (Sud-est Niger), *Agronomie Africaine 28 (2),* 2016, 25 – 37

[38]. W. E. Vissin, Impact de la variabilité climatique et de la dynamique des états de surface sur les écoulements du bassin versant béninois du fleuve Niger. *Thèse de doctorat, Université de Bourgogne. Dijon, France,* 2007, 285 p.

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