ANALYSIS OF EXTREME DAILY RAINFALL IN COTONOU

ABSTRACT: GLOBAL WARMING HAS A GLOBAL IMPACT ON THE WATER CYCLE AND IN PARTICULAR ON PRECIPITATION. THIS WORK IS DEVOTED TO THE ANALYSIS OF THE VARIABILITY OF EXTREME RAINFALL IN THE ECONOMIC CAPITAL OF BENIN. FOR THIS PURPOSE, THE 58-YEAR DAILY RAINFALL DATA COLLECTED AT THE METEO BENIN SYNOPTIC STATION IN COTONOU BETWEEN 1960 AND 2018 ARE USED. THE ANNUAL DAILY MAXIMA ~~WERE~~ WAS ESTABLISHED FOR THE ANALYSIS. THE GENERALIZED DISTRIBUTION OF EXTREME VALUES (GEV) IS USED TO ESTIMATE THE QUANTILES ACCORDING TO THE DEFINED RETURN PERIODS. THE RESULTS REVEAL THAT THE MAJORITY OF HEAVY DAILY RAINFALL DURING THE STUDY PERIOD HAS A NORMAL CHARACTER WITH RETURN PERIODS OF LESS THAN 6 YEARS. THEY ALSO SHOW ~~THAT THE FREQUENCY OF EXTREME RAINFALL~~THE EXTREME RAINFALL'S FREQUENCY HAS INCREASED VERY SLIGHTLY SINCE THE EARLY 2000S**.**

Keywords: *Extreme rainfall, GEV, return periods, flood, Cotonou.*

INTRODUCTION:

West Africa is one of the regions of the world that dramatically experiences hydro-climatic extremes due to the high variability of its climate and the high vulnerability of its population to climatic extremes ([1] and [2]). It is considered a continent particularly vulnerable to climate change, the real impact of which at the local level is still poorly understood [2]. For example, Burkina Faso and Benin experienced the most dramatic floods in their history in 2009 and 2010 respectively [3]. With enormous socio-economic consequences, these floods caused damage to housing, schools, health centers, roads, market places, places of worship, drinking water supply and sanitation networks, etc. ([4] and [5]). The specificity of the various prevention measures (information, hazard forecasting, etc.) and protection measures (construction of structures and others) require a good understanding of the hazard. We do not protect ourselves from droughts with the same measures as those used against floods [6]. Documenting hydro-climatic hazards in this part of the world is particularly important. The population is very sensitive to climatic hazards and rarely has an operational management framework to deal with the associated risks. The recurrence of floods in recent decades, for its part, shows the very high vulnerability of populations to floods [7] and also requires consideration of this hazard and the associated adaptation measures in this region of the world [6].

Benin, like all countries in the tropical zone, has experienced several heavy rains that may have played a part in the floods of recent years in the country's various cities. The constant increase in damage caused by torrential rains and floods [7] is worrying and requires a careful analysis of the seasonal cycle of rainfall through the variability of extreme rainfall. The behavior or evolution over time of extreme events is studied through several studies in Africa and around the world. Studies have mainly been based on climate indicators or indices ([8] to

[13] and [21]), frequency analysis ([14] to [24] and [29]) or by multifractal analysis ([25] to [27]).

Frequency analysis is one of the most widely used statistical approaches for modeling extreme rainfall. It is of particular interest for the management and prevention of extreme events in hydrology. It consists of studying past events in order to define the probabilities of future occurrence. The analysis of annual maximum values is therefore the one commonly used for the exploitation of available rainfall information [24]. The simplicity of its implementation, for example through Gumbel's law, has contributed to its predominance in quantifying the risk associated with extreme rainfall [24]. Many studies have been devoted to it throughout the world ([22], [24] and [28] to [30]). However, several authors ([28], [31] to [33] and [38]) have questioned at the validity of a Gumbel law, and preferred the use of the GEV law to model annual or seasonal rainfall maxima. These authors show that the Gumbel distribution can, in some cases, seriously underestimate extreme rainfall values for very long return periods. If the overestimation of quantiles directly impacts the financial cost of the works, the underestimation involves an enormous risk for the safety of hydraulic works, the validity of flood risk prevention plans or for the definition of the intensity scale of extreme events. In Benin, a recent mapping of annual maxima of daily rainfall at the national level and across thirty-five (35) stations was carried out by Ague and Afouda [33] over the period from 1921 to 2001. Apart from, for example, the unmentioned responsibility of extreme rainfall in the various floods experienced by the different cities of the country in the work, it emerges above all from the latter a dominance of the Gumbel and Lognormal laws to quantify extreme rainfall according to the return periods. In this work, the behavior of extreme rainfall is studied in the economic capital of Benin since independence (1960) until 2018. The generalized form of the distribution of extreme values (GEV) is used to estimate or quantify the quantiles of extreme rainfall according to their return period.

1. Data and Methods.

Cotonou is the economic capital of Benin and therefore the most populated city in the country. It is located further south of the country and is part of the Atlantic Ocean (Figure 1). The data used are the daily rainfall heights collected at the synoptic station (2.38 °E, 6.35 °N, Alt = 4 meters) of Meteo Benin in Cotonou between 1960 and 2018.

Figure 1: Cotonou in Benin and in Africa.

To assess the quality of the series to be independent and identically distributed, the Pettitt and Buishand break tests [34] were applied to the annual maximum series to check for possible meteorological changes. The random nature of the annual maxima of constituted rainfall is highlighted by the Kendall and Stuart rank test ([6] and [35]. These tests are retained mainly because of their ability to better detect trends compared to others [34]. The Pearson correlation tests (Alexandersson, H., 1986) and Wilcoxon homogeneity tests [36] are also applied.

After the break tests, the generalized form of the extreme value distribution (GEV) is used to estimate or quantify the return periods. The probability density function of the GEV is:

$$G(x) = \begin{cases} \exp\left\{-[-1-\frac{k}{\alpha}(x-u)]^{\frac{1}{k}}\right\} \text{ for } k \neq 0 \\ \exp\left(-\exp\left[-\frac{(x-u)}{\alpha}\right]\right) \text{ for } k = 0 \end{cases}$$

G(x) is set to $\left\{x \in R: (1-\frac{k}{\alpha}(x-u) > 0\right\}$ $with\ u \in R, \alpha > 0\ et\ k \epsilon R.$

The parameters α, u and k are respectively the position, scale and shape parameters of the GEV, are estimated by the maximum likelihood method ([6], [38] and [39). The weight of the extremes in the distribution of a variable depends on the value of the shape parameter. A positive value of this parameter indicates that the extremes do not have an important role (bounded distribution). A zero value means relatively few extremes while a negative value implies a greater number of extremes [16]. For the distributions of precipitation extremes, a negative shape parameter is often found in many regions of the world ([16], [43] and [42]). To facilitate interpretations in different applications, quantiles are expressed in terms of return period rather than probability. By definition, a return period is the average number of years between a past event and another of the same magnitude or height. There is a simple relationship between the probability of occurrence of an event corresponding to the p-quantiles and its return period T(T≥2): p = 1-1/T or T=1/(1-p). According to the international classification of extreme events proposed by the Royal Belgian Meteorological Institute [17], precipitation is classified as "abnormal", "very abnormal", "exceptional" or "very exceptional" when the return periods are at least 6 years, 10 years, 30 years, and 100 years, respectively. On this basis, quantiles of maximum daily rainfall corresponding to the return periods of 6 years, 10 years, 30 years and 100 years (with a 95% confidence interval) are calculated with the daily rainfall data collected at the Cotonou synoptic station.

2. RESULTS AND DISCUSSION

2.1 Break test

For any statistical analysis, the quality of the available data determines the relevance of the results. In order to constitute a reliable time series, free of any outliers, the daily rainfall data were carefully processed. The random nature of the annual maxima of constituted rainfall is highlighted by the Kendall and Stuart rank test. No significant break is shown by the Pettitt and Buishand tests. The low correlation rates obtained and the equality of the average of the two sub-samples with the Wilcoxon test at the 5% failure threshold highlight the homogeneity of the data from the Cotonou synoptic station. These results are in agreement with the work of Ague and Afouda [33] on most stations in the national territory between 1921 and 2001.

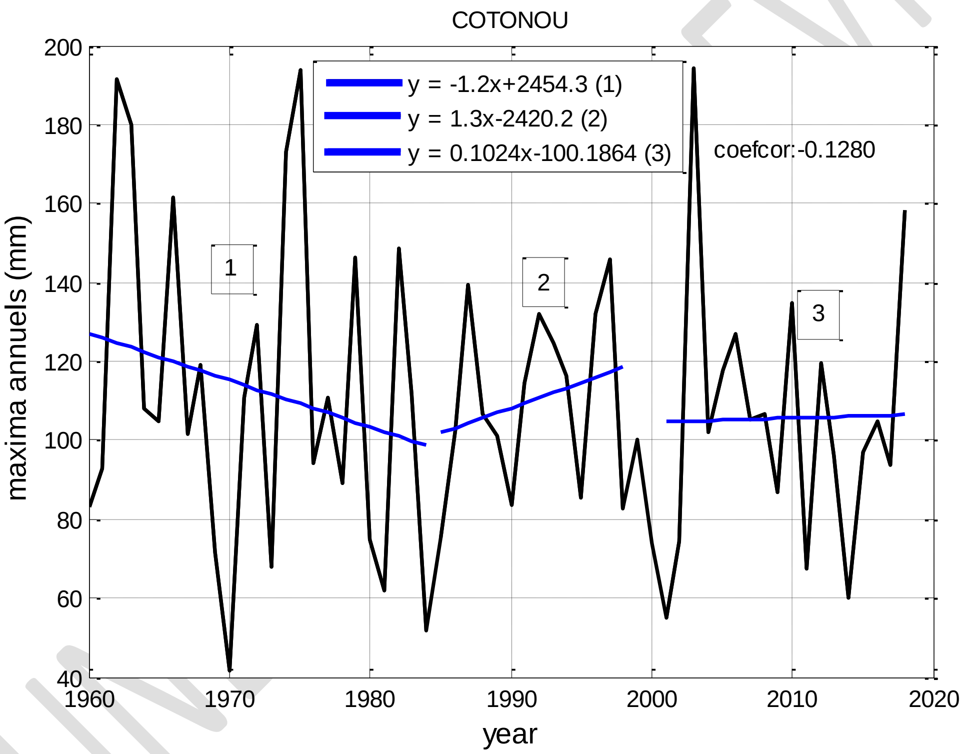

Figure 2: Variation of annual maxima.

If the variation of annual maxima in the city of Cotonou (figure 2) during the study period, do not highlight any significant trend over the study period, there is, however, a decrease in intensities observed from the beginning of the study period until the 1980s. This could be explained by climatic disturbances, especially the drought of the 1970s and 1980s ([39] and [40]) in West Africa. The downward trend is followed by a slight increase from the beginning of the 1990s until the end of the study period. This is only a consequence of the resumption of rainfall in West Africa from the beginning of the 1990s [41].

2.2 GEV applied to annual maxima

Since no significant break was detected, the GEV law was applied to the annual maxima. The negative value obtained from the shape parameter (Table 1), when GEV is applied to daily maxima, indicates the importance of the extremes in this city in southern Benin ([16], [37], [42] and [43]). Table 2 shows the quantiles estimated by return period.

Table 1: The shape, scale and position parameters calculated by maximum likelihood in Cotonou.

Parameters	Shape	Scale	Position
Cotonou	-0.0945	30.4694	93.4401

Table 2: The rain quantiles obtained with GEV.

Rainfall quantiles (in mm) obtained with GEV in Cotonou				
Station	Return period (years)			
	6	10	30	100
Cotonou	150.8382	171.2729	217.2225	272.5868

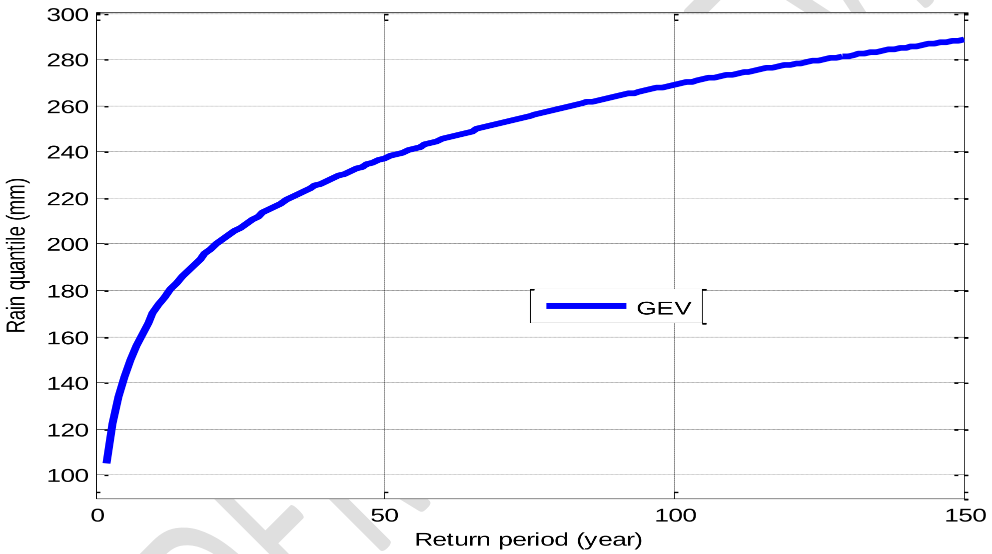

Figure 3: Quantile of rain in Cotonou according to the return periods.

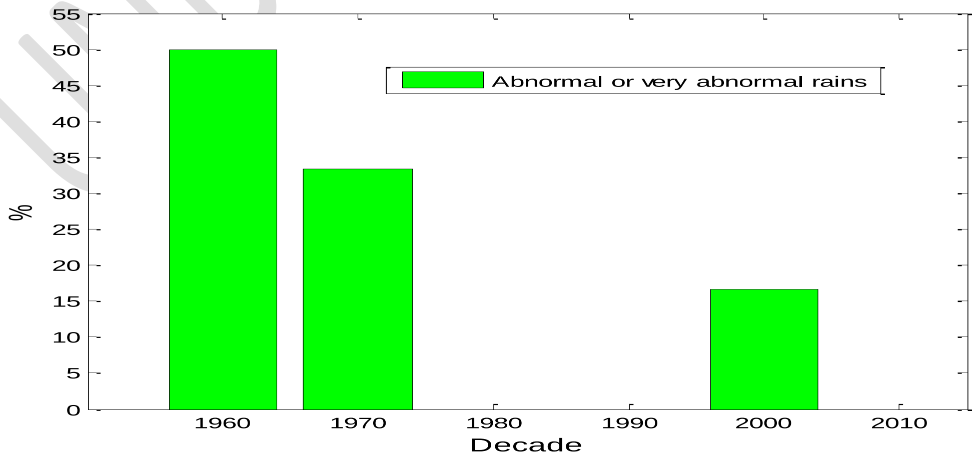

Figure 4: Proportion of abnormal or very abnormal rains by decade.

The different quantiles (Table 2) according to the return periods are evaluated over the entire study period. An analysis of the evolution of the quantiles according to the return periods (Figure 3) shows an increase in the rainfall quantiles with the return periods ([24] and [33]. These rainfall quantiles would be high for the return periods of 6 years, 10 years, 30 years and 100 years when compared to other stations in the national territory [33]. This could be due to the proximity of the city to the Atlantic Ocean. A careful analysis of the annual maxima in comparison with the estimated quantiles shows that the city of Cotonou has not experienced exceptional or very exceptional daily rainfall with return periods exceeding 30 years and 100 years respectively. But only a few rare times have abnormal or very abnormal extreme rainfall events been noted. Furthermore, the highest proportions of these types of rainfall occurred well before the droughts of the 1970s and 1980s, as shown in Figure 4. As for the 1980s and 1990s, they did not experience extreme rainfall, while the city returned to abnormal or very abnormal daily rainfall in the early years of the 21st century, but in small proportions compared to the 1960s and 1970s. The exceptional or very exceptional nature of the rainfall, even if it remains a generating element, would not play a major role in the occurrence of floods in recent years in Cotonou. The rainy episodes causing the floods, in their vast majority, have a return period of less than 6 years and therefore are not exceptional.

The floods of recent years in the city of Cotonou are thus due, among other things, to normal daily rainfall events that may have accumulated over several days. This is the case, for example, of the floods of September-October 2010, which were the most dramatic in the history [3] of the city, even on a national scale. With unprecedented socio-economic consequences on services and goods, without obscuring the loss of human life, 43 deaths and 358,621 people affected ([4] and [5]). This flood occurred following normal daily rainfall, the height of which did not exceed 70 mm in September and 45 mm in October [44]. It is therefore obvious that the slight increase in the rate of abnormal rainfall events since the beginning of the 2000s explains less the risk of flooding in the coast. However, this could be a contribution to the increase in this risk of flooding in our different cities as highlighted in the Sahel and in Senegal ([6] and [45]. These results are consistent with those of Hangnon et al. [46] in Ouagadougou and Fowe Tazen et al., [38] still in the same city.

CONCLUSION

The analysis and characterization of high intensity rainfall in subequatorial Benin, particularly in Cotonou, have allowed for a better understanding of the rainfall events that structure and modulate the annual, seasonal and daily cycles of rainfall in the country's economic capital. Almost all rainfall events in Cotonou are normal. Despite their low proportion, the proportion of abnormal rainfall has increased since the beginning of the 21st century. While not neglecting other factors, the recurrence of sometimes devastating floods on the coast is therefore caused by normal rainfall events sometimes accumulated over several days. It would therefore be necessary to consider the existence of other determining factors which, associated with heavy rainfall, lead to flooding [46] in our various cities. In the current context of global warming, our decision-makers must take into account the climate risk in the implementation of sanitation and expansion plans for our cities.

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