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Research Article

Assessing the Return Periods and Hydroclimatic Parameters for Rainwater Drainage in the Coastal City of Cotonou in Benin under Climate Variability

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Cotonou, the economic capital of Benin, is suffering from the impacts of climate change, particularly evident through recurrent floods. To effectively manage these floods and address this issue, it is crucial to have a deep understanding of return periods and hydroclimatic parameters (such as intensity-duration-frequency (IDF) curves and related coefficients), which are essential for designing stormwater drainage structures. Determining return periods and these parameters requires statistical analysis of extreme events, and this analysis needs to be regularly updated in response to climate change. The objective of this study was to determine the necessary return periods and hydroclimatic parameters to improve stormwater drainage systems in the city and its surroundings areas. This required annual maximum precipitation series of 1, 2, 3, 6, 12, and 24 h for 20 years length (1999–2018) as well as flood record data. The intensity series, derived by dividing the amount of rainfall by its duration, was adjusted using Gumbel's law. IDF curves were constructed based on Montana and Talbot models, and their coefficients were determined according to the corresponding return periods. In 2010, which witnessed devastating floods in the country, the return period for the most intense rainfall events was 40 years, followed by 2013 with a return period of 13.4 years. Consequently, the commonly used 10-year return period for the design of stormwater drainage structures in Cotonou is insufficient. The Talbot model produced the lowest mean square errors for each quantile series and coefficients of determination closest to one, indicating that the parameters obtained from this model are well suited for designing hydraulic structures in Cotonou. The hydroclimatic parameters presented in this study will contribute to the improved design of hydraulic structures in the city of Cotonou.

1. Introduction

As one of the wettest regions in Africa [1], the West African coast receives torrential rains each year, often leading to flooding. African coastal cities have witnessed an increasing number of floods in recent years, resulting in catastrophic damage [2]. To mitigate this damage, the World Meteorological Organization (WMO) encourages countries to establish flood prevention and response programs and projects. Priority should be given to risk assessment, early warning systems, risk reduction in climate-sensitive sectors, and risk finance and transfers [3]. Among these priorities, risk reduction in climate-sensitive sectors requires prevention through the implementation of structural measures (e.g., construction of stormwater drainage infrastructure) and nonstructural measures (e.g., prohibition of construction in flood zones). In West Africa, concerning structural measures, several authors [4–6] have emphasized the necessity to enhance rainwater drainage networks by densification and redevelopment of existing networks (such as collectors and retention basins). The design and sizing of these networks must account for climate change through periodic updates of relevant design parameters [7, 8]. This is essential, given the breaks observed in the hydroclimatic series before and after the 1970s and the 1990s [9, 10].

Much like many West African cities, Cotonou, Benin's most populous city, is also suffering from adverse climate change impacts, primarily manifested through recurrent floods. Managing these floods requires a comprehensive understanding of the return periods and hydroclimatic parameters essential for the design of rainwater drainage structures [11]. The requisite hydroclimatic information is typically expressed in the form of intensity-duration-frequency (IDF) curves. Previous studies have focused on establishing rainfall IDF curves and determining hydroclimatic parameters in the African tropical zone [12–14]. Among these, the most renowned is the Inter-African Committee for Hydraulic Studies (CIEH) study, which deals with rainfall-frequency curves for West and Central Africa, encompassing rainfall durations ranging from 5 min to 24 h [15]. The results of this CIEH study conducted in 1984, often employed for hydraulic structure sizing, warrant updating after four decades. Additionally, feedback from civil engineering professionals has highlighted the need for IDF curves spanning different durations (15 min, 30 min, 45 min, 1 h, 2 h, 3 h, 6 h, and 12 h), which are currently unavailable at the Benin Meteorological Agency [15].

Given the ongoing and planned initiatives for the enhancement and redevelopment of stormwater drainage networks in Cotonou [16] and other cities in the West African subregion, providing practitioners with up-to-date hydroclimatic parameters is crucial for designing rainwater drainage networks that are adaptable to the prevailing context of climate change. Therefore, the objectives of this study were to (i) determine the appropriate return periods for the design of rainwater drainage structures in Cotonou; (ii) fit a statistical model to the maximum rainfall intensity series of 1, 2, 3, 6, 12, and 24 hours; and (iii) determine hydroclimatic parameters for various return periods.

2. Materials and Methods

The methodology of this study was structured into three parts. The first part deals with the establishment of appropriate return periods for stormwater drainage in Cotonou. The second part addressed the adjustment of the statistical probability distribution to the rainfall intensity series. The third part encompasses the calculation of Montana and Talbot coefficients across various return periods and the subsequent construction of IDF curves. Before describing these three parts in detail, the next two sections provide a brief description of the study area and data used.

2.1. Research Area. The town of Cotonou is located on the coastal cordon, from which it is named the Littoral Region. With an area of 79 km^2, the municipality is located at the intersection of 6°20′ north and 2°20′ east. It is bounded to the north by Lake Nokoué, south by the Atlantic Ocean, east by the municipality of Sèmè-Kpodji, and west by the municipality of Abomey-Calavi. Cotonou's northern and southern boundaries make it a "naturally" flood-prone city. The city is the economic capital of Benin and concentrates almost all the administrative and political functions of the country [17]. The climate is subequatorial, with two alternating rainy seasons (April to July and September to November) and two dry seasons (December to March and August). The average annual rainfall is approximately 1300 mm, of which approximately half occurs in June and July [18]. Except for the Lagoon of Cotonou, the town of Cotonou has no rivers. Lake Nokoué (138 km^2) is the main water body to which several lowlands must be added (Figure 1).

2.2. Data Used. The statistical analysis of intense rainfall for flood management in urban areas requires data with fine time intervals, typically at hourly or subhourly resolutions.

However, at the Agence Météo Benin, the most detailed time step available for maximum annual precipitation data was one hour. Consequently, we collected the maximum annual rainfall data for durations of 1, 2, 3, 6, 12, and 24 h from the Cotonou-Airport station, covering a span of 20 years (1999–2018). The selection of these specific time intervals is substantiated by the average duration of intense rainfall events in the Ouémé basin, situated upstream of the city of Cotonou, which is approximately 180 min [13]. In addition to rainfall data, historical flood data for Benin were extracted from relevant literature sources [19].

2.3. Determining Return Periods for the Design of Stormwater Drainage Networks in Cotonou. The objective of this section is to determine the appropriate rainfall characteristics to consider when designing stormwater drainage networks in Cotonou and subsequently estimate their return period. A specific rainfall event had previously caused significant runoff and resultant damage in urban areas, leaving a lasting impact on the community. This historical rainfall event, which serves as a local reference, can also serve as a foundation for establishing the design rainfall criteria. To identify this historical rainfall event, rainfall intensity was calculated using the available rainfall data series and compared with historical records of flood impacts in Benin (Table 1). The identified rainfall event should exhibit the highest intensity and be associated with the most significant destructive effects. The process of determining the return period involved four key steps: (i) compiling a comprehensive dataset of rainfall intensities, (ii) calculating empirical frequencies, (iii) estimating the return period, and (iv) validating the computed return period value.

The rainfall intensity dataset was prepared by calculating the mean rainfall intensity for rainy events, then sorting, and ranking them in ascending order. Empirical frequency was computed using the Hazen formula as recommended in previous studies [20, 21].

$$F(x_r) = \frac{r - 0.5}{n}, \tag{1}$$

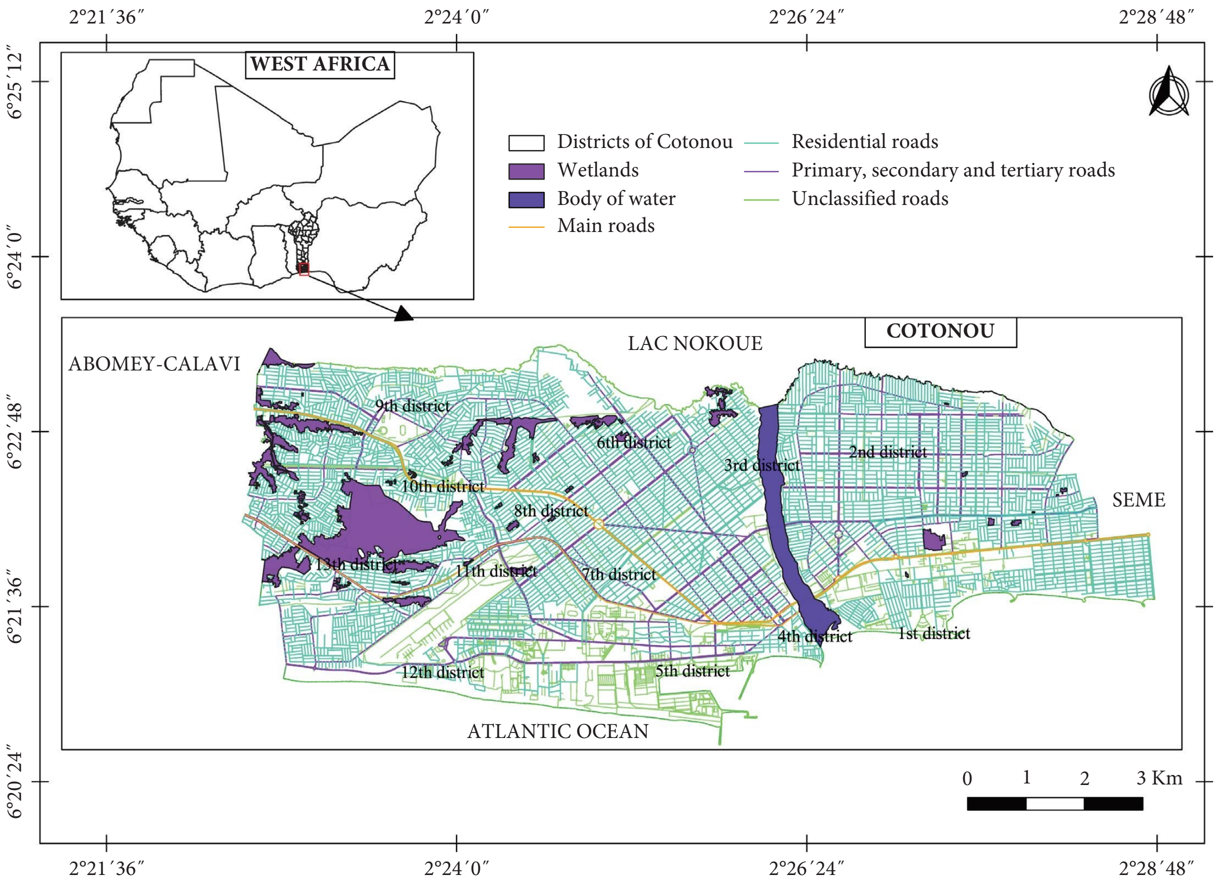

Figure 1: Location of the city of Cotonou.

where $F(x_r)$ is the empirical frequency, n is the sample size, r is the rank of the rainfall intensity values sorted in ascending order, and x_r is the rainfall intensity of ranking r.

The return period is computed using the classical formula

$$T = \frac{1}{1 - F(x_r)}, \tag{2}$$

with T the return period and $F(x_r)$ as defined above.

The maximum value of the computed rainfall intensity, derived from historical rainfall data, was validated by cross-referencing it with observations, specifically flood records in Cotonou (refer to Table 1).

2.4. Fitting a Statistical Probability Law to Rainfall Intensity Series and Estimation of Rainfall Intensity for Different Return Periods. The Gumbel distribution, widely recognized as one of the most suitable statistical models for extreme values in hydrometeorology, was selected for use in this study. The primary rationale behind this choice is its strong alignment with the rainfall maxima observed in Cotonou, as indicated in previous research [12]. The process of fitting the rainfall intensity series to the Gumbel distribution followed the conventional approach: initial preparation of the intensity data series, calculation of empirical frequencies, computation of the reduced Gumbel variable "u," and determination of the parameters of the Gumbel distribution. Consequently, the fitting process yielded estimates of rainfall intensity quantiles for various return periods.

In this section, the rainfall intensity dataset was generated by calculating the mean rainfall intensity for one-hour, two-hour, three-hour, six-hour, twelve-hour, and twenty-four-hour duration rainy events and subsequently arranging and ranking them in ascending order. The empirical frequency was computed using the Hazen formula as described in Section 2.3.

2.4.1. Computation of the Reduced Gumbel Variable u and Determination of the Parameters a and b. The reduced Gumbel variable "u" is calculated according to equation (3) for each intensity series:

$$u = \frac{x - a}{b}, \tag{3}$$

where a and b are the parameters of Gumbel's law.

The classical expression for the distribution function of the Gumbel distribution $F(x)$,

$$F(x) = \exp\left(-\exp\left(-\frac{x - a}{b}\right)\right), \tag{4}$$

becomes

Table 1: Flood records in Benin and their impacts during the last four decades.

Year	Hazard	Regions	Impacts/damages
1985	Floods	Mono, Zou, Borgou-Alibori, Ouémé-Atlantique	61 people were reported missing; 11637 houses, 651 schools, 2704 km of roads, 201 bridges, 17412 ha of farmland, 7937 tons of cereals, and 5421 heads of cattle were destroyed
1988	Floods	Zou, Borgou-Alibori	270,000 people affected, 2706 km of roads, 30,000 ha of farmland, and 25,000 tons of grain destroyed, and livestock lost
1991	Floods	Zou, Atlantique, Littoral	700,000 people were affected and 556 ha of farmland destroyed
1994	Floods	Borgou-Alibori	4600 destroyed houses and roads, 19000 ha of farmland flooded, loss of livestock
1996	Floods	Zou-Collines	147,901 people affected, roads destroyed, 1544 ha of farmland flooded, 893 tons of agricultural production lost, significant loss of livestock
1997	Floods	Atlantique, Ouémé, Mono	Destruction of houses, farms, and roads
1998	Heavy rainfall	Ouémé	Flooded farmlands
2001	Thunderstorms	Littoral	The capsizing of two boats on Lake Nokoué with loss of life
2002	Thunderstorms	Mono	Destruction of the roof of three classroom modules
2003	Heavy rainfall	Littoral	Flooded roads
	Thunderstorms	Mono	13 flooded schools
2004	Thunderstorms, floods	Littoral	Flooded roads
2005	Thunderstorms	Littoral	Houses destroyed, neighbourhoods flooded
2006	Thunderstorms	All regions	Houses destroyed, neighbourhoods flooded
2007	Thunderstorms, floods	Littoral, Mono, Northen-Benin	3476 people were affected, 1382 buildings and 5459 ha of farmland destroyed
2008	Floods	Ouémé	5 deaths, 15498 ha of farmland lost, 3190 animals dead, 17 schools and clinics flooded
2010	Floods	55 municipalities were affected to varying degrees (out of 77 in the country)	46 deaths; 680,000 people affected, of whom 150,000 needed shelter; more than 55,000 damaged houses, 455 schools and 92 health facilities partially or completely destroyed
2011–2015	Floods	All regions	25 deaths; 215 hospital admissions, 11652 houses affected, 46871 people made homeless, 140287 ha of farmland and 37339 animals lost, 259 storage units destroyed, 119 schools affected

Source: ABV-OMM-GWP initiative volta GIC [19].

$$F(x) = \exp(-\exp(-u)), \quad (5)$$

$$u = -\ln(-\ln(F(x))). \quad (6)$$

The advantage of using the reduced variable is that the expression of a quantile becomes linear,

$$x_q = a + bu_q, \quad (7)$$

allowing us to graphically determine the parameters a and b using a system of axes (u, x).

In this study, the parameters a and b were determined using the method of moments and graphical method. The graphical method has the advantage of providing visual inspection of the fitting.

Using the method of moments, the Gumbel parameters a and b are calculated according to the formulas

$$\begin{cases} b = \dfrac{\sqrt{6}}{\pi}\sigma, \\ a = \mu - b\gamma, \end{cases} \quad (8)$$

where μ and σ signify the mean and standard deviation, respectively, while, γ, represents the Euler constant, equal to 0.5772.

2.4.2. Estimation of Rainfall Intensity for Different Return Periods. To estimate the rainfall intensity corresponding to various return periods (T), an initial step was taken to compute the non-exceedance frequency utilizing the following equation:

$$\mathbf{F}(\mathbf{I}(\mathbf{T})) = \mathbf{1} - \frac{\mathbf{1}}{\mathbf{T}}, \quad (9)$$

where I represents rainfall intensity. Subsequently, the associated Gumbel reduced variable was determined using equation (6), followed by the derivation of the corresponding quantile according to the following equation:

$$\mathbf{I} = \mathbf{a} + \mathbf{b}\,\mathbf{u}, \quad (10)$$

where I, a, and b retain the same definitions as previously elucidated.

2.5. Determination of Montana and Talbot Coefficients relative to Return Periods and Construction of IDF Curves. The IDF curves served as the basis for calculating rainfall intensities for various return periods, essential in the design of flood protection structures. In this study, we considered not only the Montana model (frequently used by engineers in Benin) but also the three-parameter Talbot model, recognized as one of the most commonly employed models for establishing IDF curves [22–24].

To determine which of these two models best fits the Cotonou data, we initially determined their parameters and subsequently constructed their respective IDF curves.

Montana's empirical equation is given by

$$\mathbf{I} = \mathbf{a}\mathbf{t}^{-\mathbf{b}}, \quad (11)$$

where I is the rainfall intensity in mm/h, t is the rainfall duration in an hour, and a and b are Montana coefficients.

For the return periods (2, 5, 10, 20, 30, 50, and 100 years) and the estimated rainfall intensities corresponding to the durations (1, 2, 3, 6, 12, and 24 h), the calculation of Montana's coefficients was performed following classical practice:

(i) The logarithm is applied to equation (11) to obtain $\ln(I) = \ln(a) - b\ln(t)$. Then, we calculated $\ln(I)$ and $\ln(t)$.

(ii) The parameters of the regression line passing through the pairs ($\ln(I)$ and $\ln(t)$) were determined. The least-squares method was used to estimate the directing coefficient ($-b$) and intercept ($\ln(a)$).

(iii) The Montana's coefficient a was deduced by applying the exponential of $\ln(a)$.

The three-parameter Talbot's equation is given by

$$\mathbf{I} = \frac{\mathbf{a}}{(\mathbf{b} + \mathbf{t})^{\mathbf{c}}}, \quad (12)$$

where I and t are defined for Montana's equation and a, b, and c are Talbot's coefficients.

For the return periods (2, 5, 10, 20, 30, 50, and 100 years) and estimated rainfall intensities corresponding to the durations (1, 2, 3, 6, 12, and 24 h), the coefficients were determined according to the following steps:

(i) Set initial values for the Talbot coefficients (a, b, and c).

(ii) Calculate the corresponding maximum intensities using Talbot's formula.

(iii) Calculate the sum of the squares of the differences between the empirical and theoretical values (Talbot).

(iv) Determine the values of the Talbot coefficients (a, b, and c) that minimize the sum of the squares of the deviations (here, representing the objective function). For this purpose, an Excel optimization tool solver was used.

Once the coefficients a and b (for Montana's model) and a, b, and c (for Talbot's model) were determined, the rainfall intensities for each return period and duration considered in this study were calculated. Subsequently, IDF curves were generated for each return period using both models.

Two performance criteria, root mean square error (RMSE), as in Minh et al. [23], and coefficient of determination (R^2) [25], were used to compare both models and determine the most suitable one for Cotonou's data. RMSE is given by

$$\mathbf{RMSE} = \sqrt{\frac{\sum_{\mathbf{i}=1}^{\mathbf{n}} (\mathbf{P_i} - \mathbf{O_i})^2}{\mathbf{n}}}. \quad (13)$$

A model with R^2 closest to one and the lowest RMSE value was considered to perform the best.

3. Results

3.1. Return Periods for the Design of Stormwater Drainage Networks in Cotonou. From the 1-hour rainfall intensity series, the highest recorded value is 96.8 mm/h, which corresponds to the peak rainfall intensity in 2010. An analysis of flood records in Benin reveals that the floods in 2010 were the most devastating (refer to Table 1). While the floods in 1985 came close, they did not impact the city of Cotonou. The return period for the maximum rainfall intensity in 2010 is 40 years, followed by 2013 with a return period of 13.4 years and a maximum rainfall intensity of 93.8 mm/h. In contrast, the return periods for the maximum rainfall intensities in other years were less than 10 years (see Table 2).

3.2. Parameters of the Gumbel Law Fitted to Rainfall Intensity Series and Quantiles of Rainfall Intensity for Different Return Periods. This section presents the results of fitting the rainfall intensity series to Gumbel's law. Table 3 displays the parameters of the Gumbel law obtained through both the graphical method (refer to Figure 2) and the method of moments. The coefficients of determination in Table 3 are all close to one, indicating minimal error in the values of parameters a and b obtained using the graphical method. These values also closely align with the parameters "*a*" and "*b*" derived from the method of moments, suggesting consistency between the estimation methods despite their different approaches. The graphical method relies on visual examination and estimation, while the method of moments employs statistical calculations based on moments, as previously mentioned.

Table 4 displays the estimated rainfall intensities for the various durations and return periods assessed in this study. To prevent one-hour duration flash floods in Cotonou, it is advisable to design stormwater drainage systems with a minimum intensity of 61 mm/h. For installations intended to safeguard against rainfall events with a 100-year return period, this intensity should be doubled.

3.3. Montana and Talbot Coefficients relative to Return Periods and Corresponding IDF Curves. Table 5 provides the values of the Montana coefficients, and the corresponding IDF curves are displayed in Figure 3. It is noteworthy that while coefficient *a* exhibits an increasing trend with respect to the return period, coefficient *b* shows a slight decrease as the return period extends.

Table 6 provides a summary of the coefficients obtained from the Talbot model. Similar to the Montana model, coefficient a shows an increasing trend as the return period lengthens. However, coefficients b and c display only marginal variations with changing return periods, yet they exhibit distinct patterns. The corresponding IDF curves are presented in Figure 4.

Figures 3 and 4 confirm a well-established pattern in West Africa: the longer the rainfall duration is, the less intense the rainfall becomes. Notably, the shortest rain showers (1 hour in our case) often exhibit the highest intensity.

Table 2: Hazen probability and return period of the extreme rainfall events between 1999 and 2018.

Year	Hazen empirical probability	Rainfall intensity (mm/h)	Return period (year)
2010	0.975	96.800	40.0
2013	0.925	93.800	13.4
2003	0.875	88.000	8.0

3.4. Comparing Montana and Talbot Models. The coefficient of determination and the RMSE were selected as measures of the goodness of fit to compare the two models (Table 7). Both criteria indicate that the Talbot model, with the highest R^2 and the lowest RMSE, provides the best fit for Cotonou's data.

4. Discussion

The ten-year frequency hazard is often used for sizing stormwater infrastructures. However, in heavily urbanized areas, recognizing local hydrological risks is crucial to avoid devastating floods. This is especially important for coastal communities with significant economic interests, such as Cotonou, where coastal flooding poses additional threats [26, 27].

The investigation of short-duration rainfall intensities (1 h) reveals that the highest intensity identified in the series occurred in 2010, the year when Benin experienced unprecedented flooding, followed by 2013. The return periods determined from a 20-year sample differ significantly from the one commonly used in stormwater management in Benin (typically decennial), with variations of approximately 30 years and 4 years.

Compared to earlier studies, our analysis appears to confirm that both the study period and its length influence the values of the hydroclimatic parameters considered for sizing stormwater facilities. For example, Houngnibo's work (2013) from 1999 to 2013 (14 years) yielded similar results to those presented here (over 20 years). With an average difference of 1 mm/h for typical return periods, the Montana IDF curves provided here somewhat exceed the intensities produced by Houngnibo [15]. However, studies like Bacharou et al. [13] spanning 1971–2010 (40 years) and the CIEH study before 1984 provided different results. For instance, when considering the 10-year return period, the Montana coefficient a (93.71) obtained in this study is double that of the CIEH (45.1). Nonetheless, the Montana coefficient b varies slightly over time. For example, when considering the 10-year return period, the "b" coefficient varies minimally from 0.9 for the CIEH [14] to 0.84 for our work.

The Talbot model exhibits the lowest mean square errors for each set of quantiles and coefficients of determination closest to unity, indicating that the IDF curves and parameters provided by this model should be employed for the design of hydraulic structures in Cotonou. However, further investigation using different models is warranted to confirm the suitability of the Talbot model. Indeed, Ague and Afouda [12] found that

Table 3: Parameters of Gumbel's law derived from the method of moments and the graphical method.

Rainfall duration (hour)	Method of moments		Graphical method		
	a	*b*	*a*	*b*	Coefficient of determination (R^2)
1	56.04	12.92	56.12	13.10	0.967
2	35.24	9.01	35.26	9.20	0.980
3	24.68	7.46	24.73	7.56	0.966
6	13.34	4.24	13.37	4.29	0.965
12	7.19	2.16	7.19	2.20	0.977
24	3.78	1.06	3.79	1.07	0.965

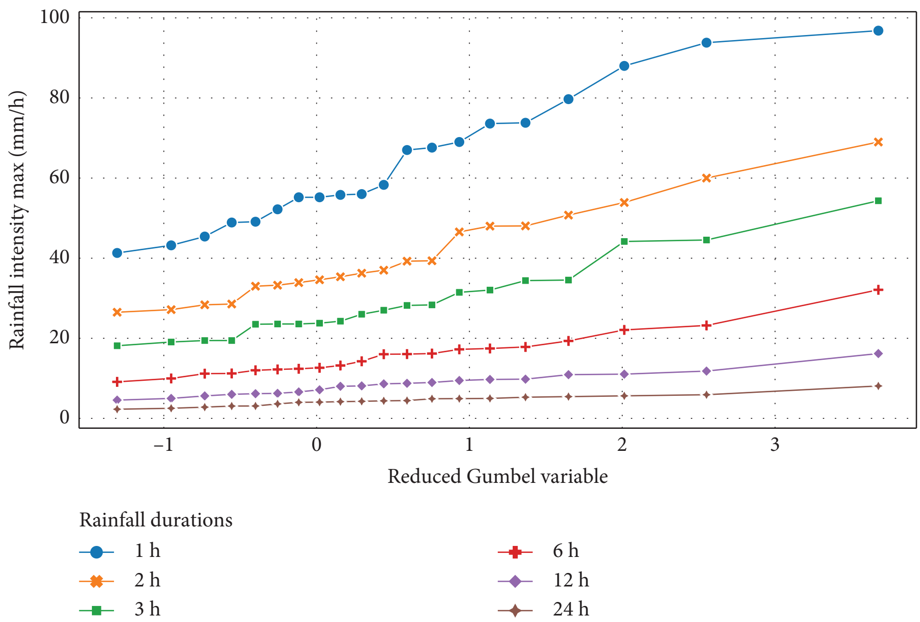

Figure 2: Graphical fitting of rainfall intensity series to Gumbel law.

Table 4: Rainfall intensity quantiles for different return periods.

Return period (year)	2	5	10	20	40	50	100
Rainfall duration (h)	Rainfall intensity (mm/h)						
1	60.5	75.5	85.4	94.9	104	107	116
2	38.4	48.2	54.8	61	67.2	69.1	75.2
3	27.3	34.9	40	44.9	49.7	51.2	55.9
6	14.8	19.7	22.1	24.8	27.5	28.4	31.1
12	8.0	10.5	12.1	13.5	15	15.4	16.8
24	4.2	5.46	6.26	7.01	7.7	8	8.7

Table 5: Montana coefficients for different return periods.

Return period (year)	2	5	10	20	40	50	100
a	65.96	82.77	93.71	104.42	114.89	118.26	128.61
b	0.85	0.83	0.83	0.83	0.83	0.83	0.82

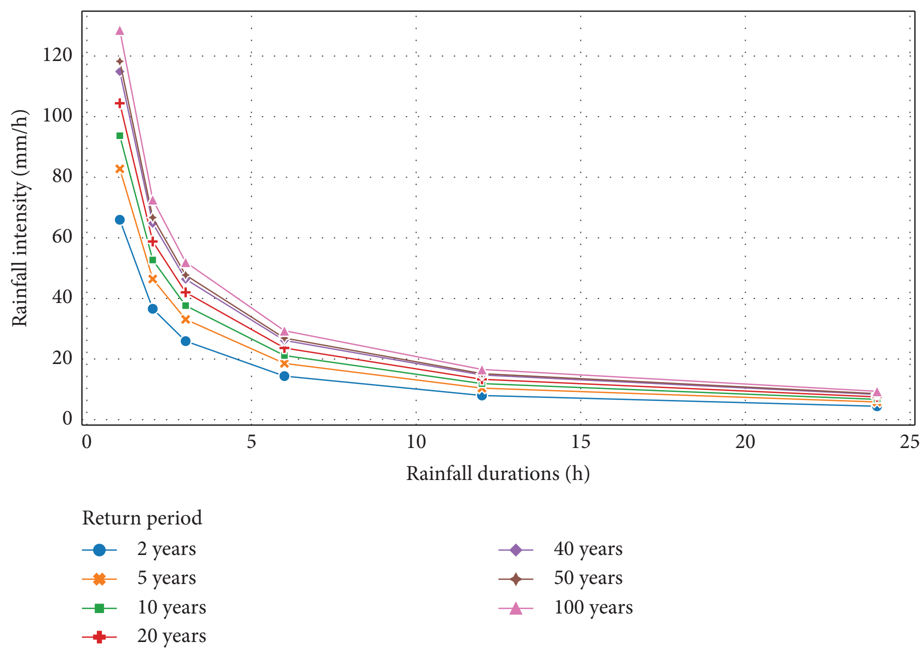

Figure 3: Montana intensity-duration-frequency curves.

Table 6: Talbot coefficients for different return periods.

Return period (year)	2	5	10	20	40	50	100
a	106.58	127.68	149.18	168.38	187.37	193.83	213.19
b	0.74	0.70	0.75	0.78	0.81	0.82	0.84
c	1.03	0.98	0.99	0.99	0.99	1	1

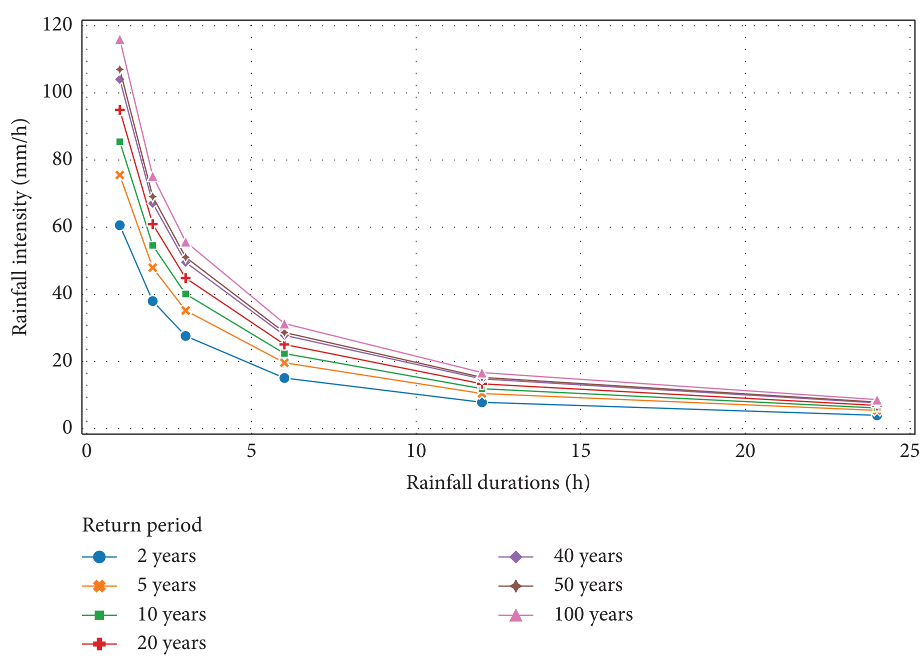

Figure 4: Talbot intensity-duration-frequency curves.

Table 7: Performance criteria used to compare the Montana and Talbot models for different return periods.

Return period (year)	Performance criteria			
	R^2		RMSE	
	Montana	Talbot	Montana	Talbot
2	0.9915	0.9998	2.4247	0.268
5	0.9913	1.0000	3.1823	0.158
10	0.9907	1.0000	3.6551	0.18
20	0.9902	1.0000	4.1899	0.144
40	0.9894	1.0000	4.792	0.158
50	0.9894	1.0000	4.9534	0.129
100	0.9887	1.0000	5.5477	0.13

RMSE stands for root mean square error.

the Keifer-Chu model outperformed the Montana and Talbot two-parameter models for stormwater drainage in Cotonou from 1954–1999 (45 years).

5. Conclusion

Given the current context of climate change, concerns have been raised about the adequacy of the rainwater drainage networks in Cotonou municipality, which were equipped according to standards established in 1984. This study aims to provide engineers with up-to-date hydroclimatic parameters for the design of stormwater facilities. The objective of this research was to determine the return periods and hydroclimatic parameters necessary for effective stormwater drainage in the city of Cotonou and its surroundings. Rainfall duration data (1, 2, 3, 6, 12, and 24 h) from the period 1999–2018 and historical flood data were utilized. To derive the intensity series, rainfall values were divided by their respective durations and fitted to the Gumbel law. IDF curves were constructed using on two models: the Montana and Talbot (Sherman) models, with coefficients determined based on return periods. The return period for the most intense rainfall in 2010 was found to be 40 years, while the subsequent precipitation had a return period of 13.4 years. These results indicate that the commonly used 10-year return period by engineers is not suitable for sizing stormwater facilities in Cotonou, confirming the hypothesis that the 10-year return period often used for storm drainage is not statistically appropriate for Cotonou. Given that the choice of return period for flood management projects is a compromise between statistics and financial considerations, we recommend a 40-year return period for projects with a high risk of flood damage and a 14-year return period for medium-risk projects. Montana and Talbot coefficients were calculated for various return periods, and IDF curves derived. The Gumbel law exhibited a good fit with the series of annual maximum intensities, confirming both assumptions. The Talbot model produced the lowest mean square errors for each set of quantiles and coefficients of determination closest to unity. Therefore, it can be concluded that the IDF curves and parameters obtained using the Talbot model are suitable for the design of hydraulic structures in Cotonou.

We aim to further investigate the return periods by conducting multiple scenarios using simulation software for modelling the behaviour of Cotonou's catchment areas and their stormwater drainage networks. These software packages, which have undergone significant developments, will confirm the appropriate return periods to be used. Additionally, it would be of interest to deepen the ongoing work by considering longer data series, including rainfall durations of less than 1 hour, and exploring alternative probability distributions beyond the Gumbel law, as well as alternative models for constructing IDF curves other than those of Montana and Talbot.

Data Availability

The data that support the findings of this study are available on request from the Benin Meteorological Agency (https://meteobenin.bj/services/demande-de-donnees/). The data are not publicly available due to policy restrictions.

Disclosure

This work was performed as part of the research activities of the Laboratoire d'Hydrologie Appliquée de l'Université d'Abomey-Calavi and the Laboratoire des sciences végétales, horticoles, et forestières de l'Université Nationale d'Agriculture du Bénin.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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