

Modeling Intensity–Duration–Frequency Curves for Rainstorms in the Cities of Tabligbo and Atakpamé, Southern Togo

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ABSTRACT

Reducing flood-related disaster risk requires an understanding of climatic factors such as rainfall, and in particular, storm intensities. Intensity–duration–frequency (IDF) curves are therefore an indispensable tool for sustainable urban planning specialists. An analysis of the storm intensity characteristics of the cities of Tabligbo and Atakpamé in southern Togo was carried out. Pluviographic data from the Tabligbo and Atakpamé stations were collected over periods of 18 and 16 years, respectively. The various distribution fits were assessed using the chi-square (χ^2) and Anderson–Darling tests. The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) showed that the Gumbel distribution (GEV I) best describes short-duration rainfall of 5 and 10 minutes for Atakpamé, and durations shorter than 55 minutes for Tabligbo. Longer-duration rainfall—greater than 40 minutes for Atakpamé and 60 minutes for Tabligbo—follows the GEV III distribution. A comparison of the root means square errors and correlation coefficients of four empirical equations (Montana, Talbot, Keifer & Chu, and Wanielista) showed that the Keifer & Chu formula best describes the maximum average rainfall in the cities of

Atakpamé and Tabligbo. The Montana formula, commonly used in previous models, remains effective for the city of Atakpamé, but for the city of Tabligbo it produces larger quadratic errors than the other formulas. Accordingly, intensity–duration–frequency (IDF) curves were established for the cities of Atakpamé and Tabligbo for return periods of 5, 10, 20, 50, and 100 years.

Keywords: Modeling, maximum precipitation, Intensity–Duration–Frequency, Atakpamé, Tabligbo, Southern Togo.

INTRODUCTION

Worldwide, 2019 saw 308 disasters caused by natural hazards (violent winds, floods, wildfires, extreme temperatures), affecting 97.6 million people and causing 24,396 deaths (Revet and Metzger, 2024). Urban flooding that follows heavy rainstorms remains the most visible illustration of the impacts of extreme climatic events. Several African cities, having only just emerged from a long period of drought, immediately face severe flooding of unprecedented magnitude (Meva'a et al., 2010). All African cities are, to varying degrees, vulnerable to flooding and each adapts in its own way. In addition to the usual challenges—lack of

infrastructure (housing, energy, communication)—there are further challenges related to disaster management and the organization of relief efforts (Hauhouot, 2008). West Africa has experienced an increase in flooding in recent years. Droughts, floods, storms, epidemics, and transportation accidents have caused the greatest losses of life, livelihoods, and essential infrastructure, and have had the largest economic impact. Droughts, storms, and transportation accidents have remained relatively stable, while flooding has doubled. Disaster-related mortality (from storms, floods, and epidemics) in Africa increased from 22,330 in 2017–2018 to 42,275 in 2019–2020. Direct economic damages from disasters were estimated at 1.1 billion dollars in 2017–2018, and then at 786 million dollars in 2019–2020 (AU, 2024).

In Togo, floods have been recorded earlier than in other countries in the subregion. They have severely affected road infrastructure and socioeconomic facilities. In 2007, Togo recorded, in two of its administrative regions (Maritime and Savanes), 42 deaths, 245,869 people affected, 51,902 homes destroyed, 31 health facilities, 1,176 classrooms, and 10,957 ha of crops damaged, as well as 23,061 head of livestock lost. In 2024, 19 flood-related disasters and 6,775 violent-wind events were recorded, affecting 476 internally displaced persons (ANPC, 2024). However, few scientific studies have been devoted to disaster prevention. Not only do the same areas and the same populations suffer increasingly severe damage each year, but new localities and populations are becoming highly vulnerable to flooding as well (Gbafa et al., 2017).

Rainfall remains the primary factor implicated in flood-related natural disasters. Rainfall variability is generally expressed through mean maximum rainfall depths, but also through the frequency and intensity of extreme rainfall in each region. Short-duration extreme precipitation is indeed the main cause of the sudden, catastrophic

floods that can occur in many small watersheds. The first genuine study on this subject (Valls, 1984) produced depth–duration–frequency curves for the city of Lomé, for return periods of 1, 2, 5, 10, and 20 years. Other studies (Goula et al., 2007; Mohymont and Demarée, 2006) have shown not only that storms in certain African cities follow distribution laws that differ from one duration to another, but have also rejected the Montana formula, which is commonly used to establish IDF curves. Which laws, then, best describe storms in the major cities of southern Togo as a function of duration? And which formula produces the best IDF curves? The present study therefore aims to characterize maximum storm intensities and to model the IDF curves for the cities of Atakpamé and Tabligbo in southern Togo.

MATERIALS & METHODS

Study Area

The city of Atakpamé, also known as the “City of Seven Hills,” is in central Togo, in the Plateaux Region, of which it is the capital. An important crossroad between the south and north of the country, Atakpamé lies on the main national road linking Lomé, the capital, to the hinterland countries. Atakpamé is one of the major cities of Togo in terms of population and urban importance, with an estimated population of more than 116,301 inhabitants (RGPH, 2023). The city is located at approximately 7°58′ north latitude and 1°12′ east longitude (Figure 1). The average elevation ranges between 250 m and 400 m. Atakpamé have a tropical climate, marked by two main seasons: a rainy season from April to October and a dry season from November to March. Atakpamé is a commercial, administrative, and transit hub at the heart of a dynamic agricultural area (Barbier, 1983).

The city of Tabligbo is in southern Togo, in the Maritime Region. The city lies at approximately 6°35′ north latitude and 1°30′ east longitude, with an average elevation of about 44 to 76 m (Figure 1). Tabligbo has a Sudano-Guinean tropical climate of the

savanna type, characterized by a rainy season from April to October and a dry season from November to March, influenced by the harmattan during the dry

season. The city has approximately 41,803 inhabitants (RGPH, 2023), and its main economic activities are agriculture, livestock farming, trade, and handicrafts.

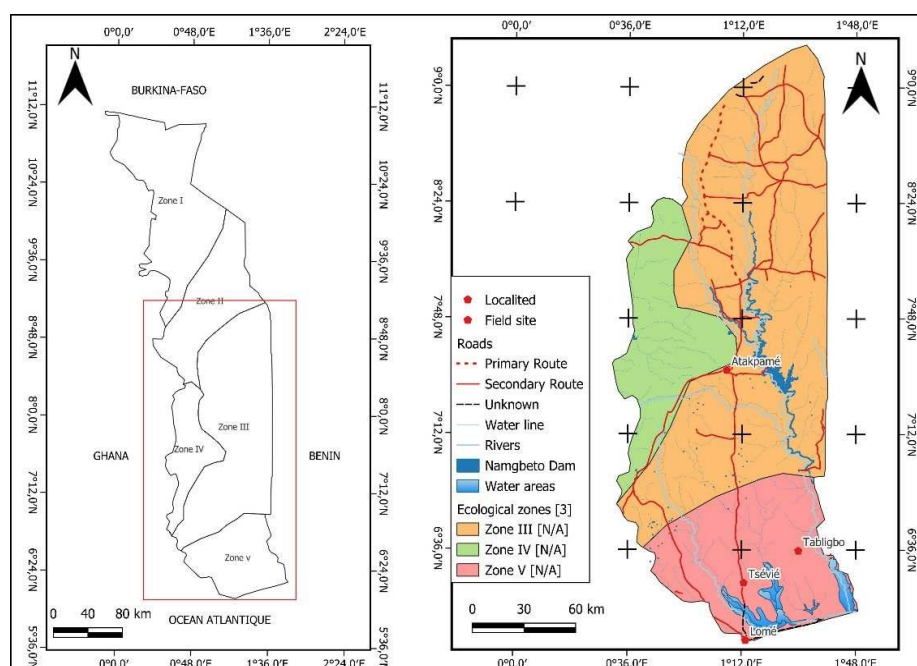


Figure 1: Study area

Rainfall Data Collection

The data were obtained from systematic processing of pluviograph records from the Atakpamé and Tabligbo stations (Binguitcha-Fare, 2003), covering 16 and 14 years of data at Atakpamé (1980–1997) and Tabligbo (1980–1993), respectively. In total, more than 1,515 rain-days were computed using the R Studio (2025) environment, and the results were exported as Microsoft Excel data files or JPEG graphics.

Extreme Value Probability Distribution and Statistical Selection Criteria

The purpose here is to determine the distribution law that best describes a storm of a given duration. The three most used models were applied to each storm event: the Log-normal distribution (Goula et al., 2007), GEV I (Gumbel), and GEV III (Coles et al., 2003). The tests performed were the Kendall stationarity test (Yue and Pilon, 2004) to detect trends in the series, and the Wald–Wolfowitz independence test (Haché et al., 1999) to check for sequential dependence in the observations.

Table 1: Characteristics of the GEV distribution family (Mohymont and Demarée, 2006)

k_i	Type	Common name of the distribution	Lower bound	Upper bound
> 0	III	GEV III, Weibull	$-\infty$	finite
$= 0$	I	GEV I, Gumbel	$-\infty$	$+\infty$
< 0	II	GEV II, 3-parameter Fréchet	finite	$+\infty$

The statistical criteria used to compare the distribution laws were the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) (Lebarbier and Mary-Huard, 2004). In the

expression of each of these laws, a and b represent, respectively, the location and scale (dispersion) parameters (Table 1). The best model is the one whose fitted distribution has the lowest criterion value

(AICc and BIC). The models were then ranked ranging from most suitable (No. 1) to least suitable (No. 3).

Modeling of Intensity–Duration–Frequency Curves

Montana Model

This is one of the most widely used models in the field, owing to its simplicity relative to other models (Mohyont and Demarée, 2006). For a given return period T , this model is expressed by equation (E1):

$$i(t, T) = a(T) / t^b(T) \quad (E1)$$

where a is the location parameter and b is the dispersion parameter.

Talbot Model

The Talbot model is recommended in Swiss professional road-design standards (Mohyont and Demarée, 2006). For a given return period T , the model is expressed by equation (E2):

$$i(t, T) = a(T) / (t + b(T)) \quad (E2)$$

Keifer–Chu Model

The Keifer–Chu model is like the Talbot model, but is more robust owing to the introduction of a third parameter, following equation (E3):

$$i(t, T) = a(T) / (t + b(T))^c(T) \quad (E3)$$

where a , b , and c are fitting parameters.

Wanielista Model

This is the general model, and it therefore combines the other three models, which are simplifications of it, into a single equation. Unlike the others, it can be used to plot all the curves with a single formula, given by:

$$i(t, T) = a(T) \times T^n / (t + b(T))^c(T) \quad (E4)$$

where a , b , c , and n are fitting parameters and T is the return period.

Selection of the Best IDF Model

Correlation Coefficient (R)

The correlation coefficient R is used to assess the linear relationship between the theoretical and observed data. This coefficient is given by equation (E5) and ranges from -1 to 1 . It also allows different fits to be compared:

$$R = \sum (x_i - \bar{x}) (y_i - \bar{y}) / \sqrt{[\sum (x_i - \bar{x})^2 \times \sum (y_i - \bar{y})^2]} \quad (E5)$$

where x is the observed value and y is the theoretical value.

Mean Square Error (MSE)

The mean square error is used to compare several fits and to identify the best one, which is the one with the lowest MSE. It is expressed by equation (E6):

$$MSE = (1/n) \times \sum (x_i - \hat{x}_i)^2 \quad (E6)$$

where x is the observed value and $\hat{x}$ is the theoretical (predicted) value.

RESULT AND DISCUSSION

Fitting of Distribution Laws for Rainfall Intensities in Atakpamé and Tabligbo

For the distribution of rainfall intensities in Atakpamé, the Anderson–Darling statistic is constant ($A = 2.357$, $A_{crit} = 0.719$) across all three distribution laws. The chi-square test also gives $P = 0$ for all distributions. The same pattern is observed for rainfall intensities in Tabligbo ($A = 0.6665$, $A_{crit} = 0.7124$) across all three laws. Rainfall intensity data do not always follow the

distribution laws in the same manner. For the 5-minute rainfall to fit, all three laws produce similar distributions that all appear to describe the data well. For the 35-minute rainfall fit, the situation is quite different: the Log-normal and Gumbel distributions diverge from the observed data. This divergence is much more pronounced in the tail of the distribution.

Ranking of Rainfall Intensity Fits

Ranking of Rainfall Intensity Fits for the City of Atakpamé

The preceding fits show that the most suitable frequency models are:

- The Gumbel distribution for maximum average rainfall intensities of 5, 10, and 15 minutes.
- The Log-normal distribution for maximum average rainfall intensities from 20 to 45 minutes.

- The GEV III distribution for maximum average rainfall intensities from 50 to 120 minutes.

Table 2: Ranking of the best frequency models for rainfall intensities in Atakpamé

Rainfall duration (min)	Rank No. 1	Rank No. 2	Rank No. 3
5, 10, and 15	Gumbel	Log-normal	GEV
20	Log-normal	GEV	Gumbel
25	GEV	Log-normal	Gumbel
30 to 45, in 5-min steps	Log-normal	GEV	Gumbel
50 to 120, in 5-min steps	GEV	Log-normal	Gumbel

It is observed that the Log-normal and Gumbel distributions describe the maximum average intensities of short-duration rainfall well, while the Log-normal and GEV distributions better describe those of medium and long duration. The Gumbel distribution ranks third for rainfall durations longer than 20 minutes. No single frequency model can best describe all the data series from a weather station, which is why several must be used to identify the most suitable ones. These results further confirm the complexity of analyzing maximum average rainfall intensities (Goula et al., 2012; Andrieu et al., 1993; Gbafa et al., 2017).

Ranking of Rainfall Intensity Fits for the City of Tabligbo

The preceding fits show that the most suitable frequency models are:

- The Gumbel distribution for maximum average rainfall intensities from 5 to 70 minutes.
- The GEV distribution for maximum average rainfall intensities from 75 to 120 minutes.

The Gumbel distribution describes the maximum average intensities of short- and medium-duration rainfall well, while the GEV distribution better describes those of long duration.

Table 3: Ranking of the best frequency models for rainfall intensities in Tabligbo

Rainfall duration (min)	Rank No. 1	Rank No. 2	Rank No. 3
5 to 45, in 5-min steps	Gumbel	Log-normal	GEV
50 to 70, in 5-min steps	Gumbel	GEV	Log-normal
75 to 105, in 5-min steps	GEV	Gumbel	Log-normal
110 to 120, in 5-min steps	GEV	Log-normal	Gumbel

Modeling of the IDF Curves

Modeling of the IDF Curves for the City of Atakpamé

The first step is to examine the linear dependence between the model outputs and

the quantiles, using the mean square errors and the coefficient of determination (Table 4).

Table 4: Mean square errors (MSE) and coefficient of determination (R^2) — Atakpamé

Return period	Model	MSE	R^2
10 years	Montana	0.0087	0.9886
	Talbot	0.0071	0.9912
	Keifer–Chu	0.0025	0.9966
	Wanielista	0.0065	0.9912
20 years	Montana	0.0047	0.9952
	Talbot	0.0179	0.9840
	Keifer–Chu	0.0028	0.9970
	Wanielista	0.0043	0.9966
50 years	Montana	0.0052	0.9959
	Talbot	0.0437	0.9720
	Keifer–Chu	0.0052	0.9959
	Wanielista	0.0070	0.9949

100 years	Montana	0.0123	0.9921
	Talbot	0.0746	0.9612
	Keifer–Chu	0.0104	0.9933
	Wanielista	0.0178	0.9890

The maximum MSE (0.0746) and the minimum coefficient of determination (0.9612) are both obtained for the Talbot formula, for the 100-year return period. This confirms that all the models exhibit a strong linear correlation with the observed quantiles. The Montana formula, previously rejected for establishing the IDF curves for the city of Lomé (Gbafa et al., 2017), proves to be appropriate for the 20-, 50-, and 100-year return periods here.

Modeling of the IDF Curves for the City of Tabligbo

The maximum mean square error is 0.0519, and the minimum coefficient of determination is 0.9525 (Table 5). Overall, it can therefore be concluded that all the models exhibit a strong linear correlation with the observed quantiles. The Talbot and Keifer–Chu formulas give the best results compared with the Montana formula.

Table 5: Mean square errors (MSE) and coefficient of determination (R^2) — Tabligbo

Return period	Model	MSE	R^2
10 years	Montana	0.0494	0.9439
	Talbot	0.0136	0.9845
	Keifer–Chu	0.0120	0.9857
	Wanielista	0.0168	0.9855
20 years	Montana	0.0511	0.9525
	Talbot	0.0166	0.9840
	Keifer–Chu	0.0166	0.9840
	Wanielista	0.0190	0.9842
50 years	Montana	0.0516	0.9615
	Talbot	0.0256	0.9803
	Keifer–Chu	0.0234	0.9820
	Wanielista	0.0250	0.9814
100 years	Montana	0.0519	0.9662
	Talbot	0.0388	0.9746
	Keifer–Chu	0.0298	0.9801
	Wanielista	0.0394	0.9778

Parameters of the IDF Curves for the Cities of Atakpamé and Tabligbo

Following the Keifer–Chu formula, all three parameters (a, b, and c) decrease as the

return period increases for the city of Atakpamé (Table 6).

Table 6: Parameters of the IDF curves for the city of Atakpamé according to the Keifer–Chu and Montana formulas

Model	T	5 years	10 years	20 years	50 years	100 years
Keifer–Chu	a	48.19	23.03	17.22	14.63	13.84
	b	12.67	5.143	1.943	−0.1587	−1.086
	c	0.9249	0.739	0.6484	0.5799	0.545
Montana	a	—	—	12.66	15.03	16.79
	b	—	—	0.5758	0.5864	0.592

However, for the city of Tabligbo, these parameters do not follow the same pattern, and in addition, parameter a take on very large values.

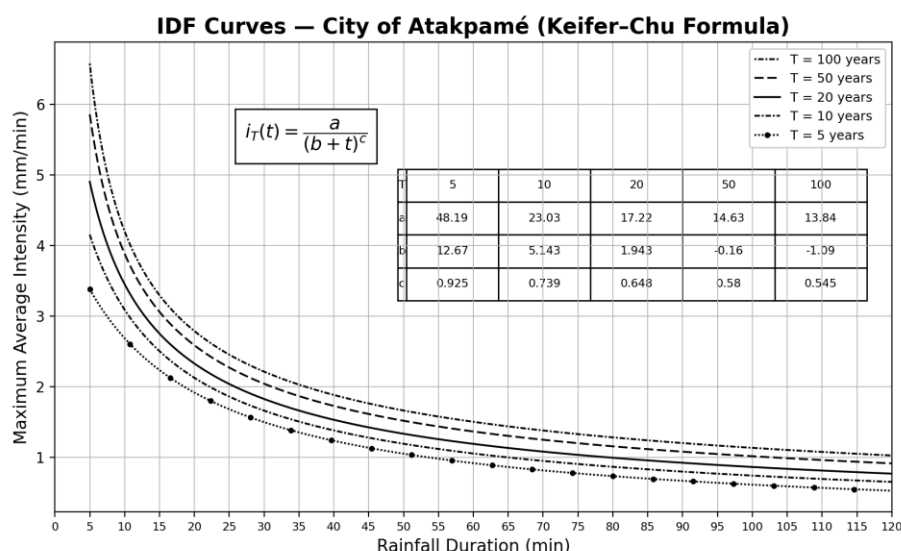


Figure 2: IDF curves for the city of Atakpamé according to the Keifer–Chu formula

Table 7: Parameters of the IDF curves for the city of Tabligbo according to the Keifer–Chu and Talbot formulas

Model	T	5 years	10 years	20 years	50 years	100 years
Keifer–Chua	a	2151	334.9	121.3	55.22	37.81
	b	42.81	27.8	19.01	11.78	8.127
	c	1.669	1.269	1.03	0.8254	0.7161
Talbot	a	71.93	88.15	104.8	128.3	147.7
	b	15.31	16.54	17.74	19.4	20.78

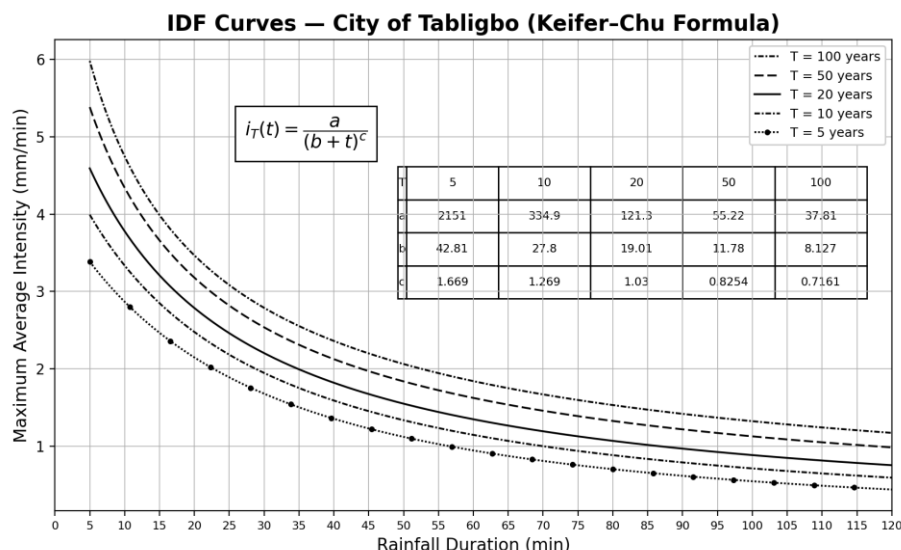


Figure 3: IDF curves for the city of Tabligbo according to the Keifer–Chu formula

A comparison between the IDF curves obtained in this study and the earlier IDF curves (Binguitcha-Fare, 2003), for the 10-year return period, shows on the one hand that the earlier curves overestimate rainfall for durations between 5 and 15 minutes and between 70 and 120 minutes. On the other

hand, the earlier curves underestimate rainfall for durations between 15 and 70 minutes.

Several factors could explain the discrepancy observed between the IDF curves from the two studies. First, the earlier study relied on a single distribution

law (Gibrat–Galton) fitted graphically on paper. This methodology does not allow quantiles to be determined with good precision. Indeed, the present study demonstrated the need to use several distribution laws to identify the most suitable one. This finding is also confirmed by several earlier studies (Andrieu et al., 1993; Goula et al., 2010), which recommend using multiple distribution laws to identify those best suited to the data series. These discrepancies between the curves are also attributable to the use of the Montana model in the earlier curves. The present study found the Montana model to be well suited to modeling the IDF curves for the city of Atakpamé for the 20-, 50-, and 100-year return periods. However, the Talbot and Keifer–Chu models are the best overall for both cities.

CONCLUSION

The present study made it possible to model the IDF curves for the cities of Atakpamé and Tabligbo in Togo, enabling designers to determine design storms for the optimal sizing of stormwater drainage structures. The analysis of the rainfall data series involved, first, digitizing the available data, which were then fitted using the Log-normal, Gumbel, and GEV distribution laws. These fits were then checked using the χ^2 and Anderson–Darling tests to determine the best-fitting distributions. Finally, based on the Akaike (AIC) and Bayesian (BIC) criteria, the most suitable distribution laws were determined for the distribution of maximum average rainfall intensities in Atakpamé and Tabligbo, Togo.

Modeling the IDF curves involved, first, determining the quantiles for return periods of 10, 20, 50, and 100 years. These quantiles were then modeled using the Montana, Talbot, Keifer–Chu, and Wanielista formulas. Based on the mean square error and the correlation and determination coefficients, the best IDF model identified was the Keifer–Chu formula.

The present study provides urban planning professionals with IDF curves, thereby

contributing to reducing flood risk in the cities of Atakpamé and Tabligbo, Togo, and to their long-term sustainability.

Declaration by Authors

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