Analysis of the Occurrence of Extreme Rainfall and Hydrological Events in the Cavally River watershed (Western Côte d'Ivoire)

BROU Loukou Alexis[1], KOUASSI Kouakou Lazare[2], KOUADIO Zilé Alex[3], Abdoulaye BARRY[4], KONAN Kouakou Séraphin[5], KONAN Koffi Félix[6]

[1, 2, 3, 5, 6]Laboratoire des Sciences et technologies de l'Environnement, Université Jean Lorougnon GUEDE, Daloa

[4]Institut Supérieur Agronomique et Vétérinaire (ISAV) de Faranah, Guinée ; Correspondant: BROU Loukou Alexis

Abstract: ***In Côte d'Ivoire, the lack of knowledge of flows at the outlet of basins and the frequency of floods sometimes lead to poor sizing of hydraulic structures. The Cavally River watershed has suffered in recent years from recurrent flooding phenomena that cause significant damage to the population. The objective of this study is to analyse the occurrence of extreme rainfall and hydrological events that may occur in the Cavally River watershed located in western Côte d'Ivoire. To achieve this objective, daily data from three (03) hydrometric stations located on the Cavally River and three (03) rainfall stations were used. To do this, three (3) statistical methods of frequency analysis (Gumbel, Fréchet and Weibull) were adopted. These analyses show that the statistical law that best fits the series of maximum flows and maximum rains is the Weibull law. Project rains of 2; 5; 10; 10; 20; 50 and 100 years are 91.2; 133; 160; 187; 221; 246 mm respectively. The project flows are 246; 293; 316; 334; 353 and 365 m^3/s respectively for the return periods of 2; 5; 10; 20; 50 and 100 years. These results could guide decision-making on the design of hydraulic structures in the western region of Côte d'Ivoire.***

Keywords: Frequent analysis,hydrological and rainfall extremes, return period, Cavally River

1. Introduction

Rainfall and hydrological extremes (drought and flooding) have become increasingly recurrent and worrying for populations in recent years[1].Therefore, knowledge of these extreme events is essential in the planning and design of important infrastructure, such as reservoirs, dams, diversion channels, bridges, etc. [2], [3]. This knowledge necessarily requires the implementation of statistical models to predict floods and low water levels in a watershed. However, the choice of the ideal law for quantile estimation is the real problem in applied hydrology. The Cavally River watershed has suffered recurrent flooding in recent years, causing major damage to the population. In the face of all these events, the implementation of reliable statistical models is necessary to enable decision-makers to have accurate and up-to-date information in the design of hydraulic structure construction projects. In this perspective, several studies have already been carried out both in the world [4]–[7] and in Côte d'Ivoire through regional statistical models [2], [8]. Unfortunately, these statistical models tend to overestimate or underestimate extreme rainfall and hydrological events, hence the need to use local statistical laws that adjust better by minimizing errors and biases [9], [10]. In the Cavally River watershed, a study on the prediction of flows in response to rainfall has already been carried out [11]. Although for a quantity of rainfall falling on the Cavally catchment area, the flow at the outlet is known, the occurrence of these future rainfall and hydrological events is almost unknown. The objective of this paper is to analyze the occurrence of extreme rains and flows in the Cavally River watershed through local statistical models.

2. Material et Methods

2.1. Presentation of the study area

The Cavally watershed is one of the transboundary basins of West Africa. It is shared between Guinea, Côte d'Ivoire and Liberia. The Cavally River originates in Guinea, north of Mount Nimba, at an altitude of more than 1000 m (Figure 1). It is 700 km long and serves as the border between Liberia and Côte d'Ivoire from its middle course (south of Toulépleu) for about 330 km. The watershed has a total area of 28,800 km^2 at Taté, a hydrometric station located 60 km from the mouth. In Côte d'Ivoire, cavally drains an area of 15,000 km^2[12].

For the purpose of this study, the outlet chosen is the Floleu hydrometric station with an area of 3647 km^2 located downstream of the Ity station in the Zouan-Hounien region (Figure 1).

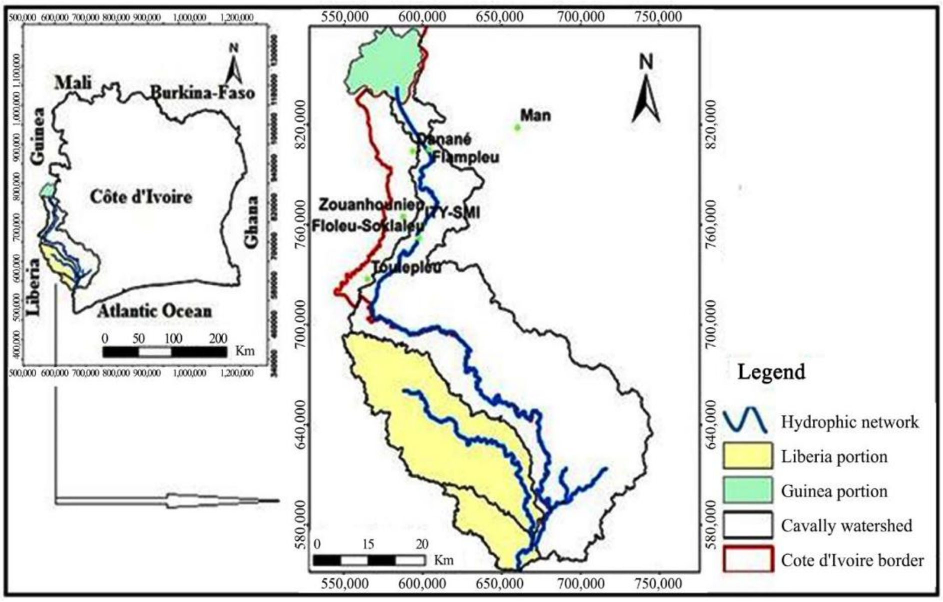

Figure 1: Geographical location of the Cavally River watershed

2.2. Environmentalcontext

The Cavally watershed belongs to two types of climate: the mountain climate in its northern part up to Zouan-Hounien and the equatorial transition climate in its southern part from Toulépleu to the mouth. This northern part of the basin (Figure 2), which is the subject of this study, is a forest area characterized by a mountain climate with two seasons.

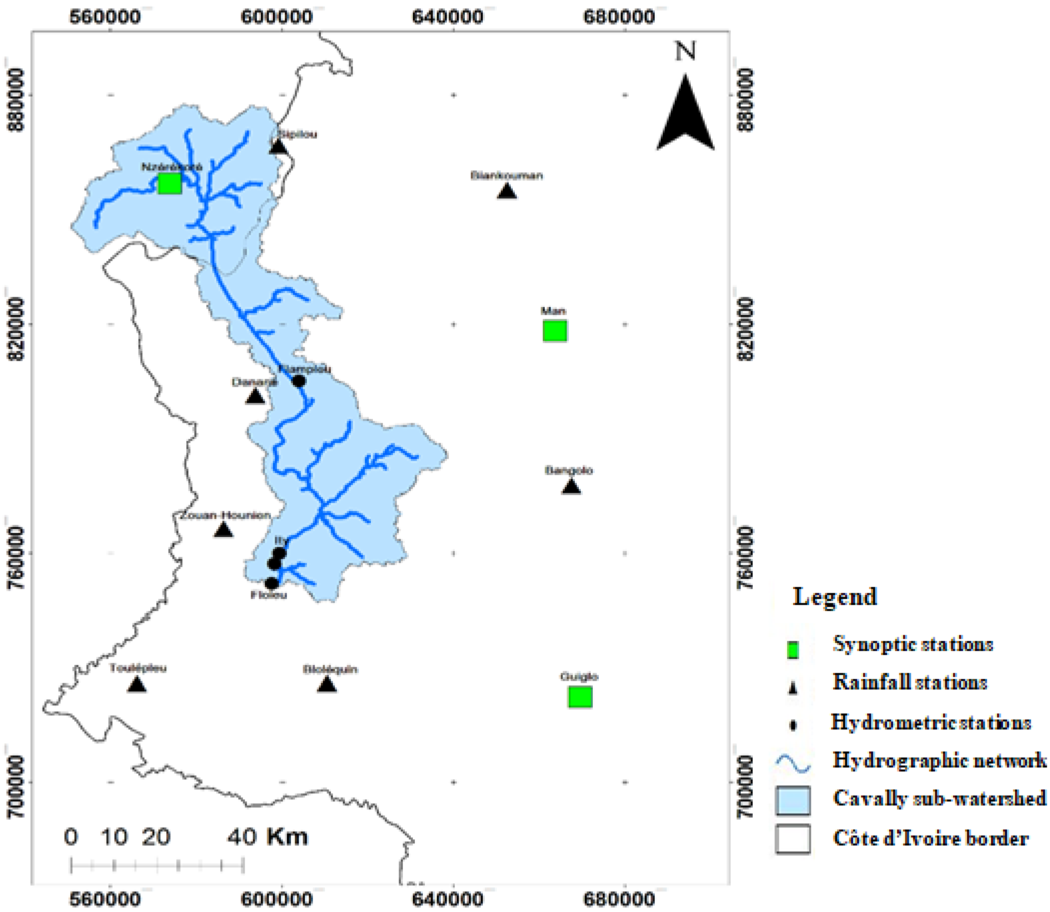

Figure 2: Cavally sub-watershed including hydromeric and rainfall stations

A rainy season from March to October and a dry season from November to February with an average annual rainfall of 1866 mm (1970-2010). The least rainy month is January with an average rainfall below 15 mm. September is the wettest month with an average rainfall of 236 mm. The average annual temperature is 25.6°C (Figure 3). This regime is close to the boundaries between the tropical transition and equatorial transition type [11].

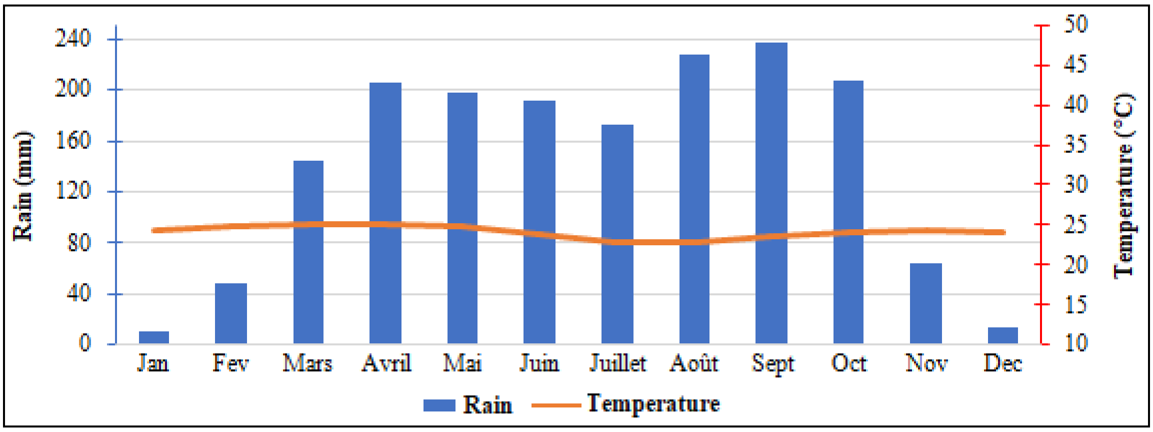

Figure 3 : Umbrothermal diagram of the station of Zouan-Hounien

2.3. Data collection and analysis

The data used are hydrometric and rainfall data at daily time steps. Flow and water level data are from three (3) Flampleu, Ity and Toulepleu hydrometric stations. The rainfall data are those of the Danané and Zouan-Hounien stations. The daily flow data come from the General Directorate of Infrastructure and Human Hydraulics (DGIHH) under the supervision of the Ministry of Economic Infrastructure of the Republic of Côte d'Ivoire. The dailyrainfall data wereacquiredfrom the Société de Développement et d'Exploitation Aéroportuaire et Maritime (SODEXAM). The data collection periods are recorded in Table 1.

Table 1: Hydrometric and rainfall stations used according to the data collection period

Stations	Type of stations	Type of data	Collection period
Flampleu	Hydrometrics	Daily flows	1955-2001 (46 years)
Ity			1980-2001 (21 years)
Toulépleu			1970-2004 (34 years)
Zouan-Hounien	Rainfall	Daily rainfall	1970-2018 (48 years)
Danané			1997-2018 (21 years)
Nzerekouré	Synoptic	Monthly rain, temperature and relative humidity	1961-2018 (57 years)

2.4. Methods

2.4.1. Mapping of annualaveragerainfall

The average rainfall distribution was calculated using the isohyet method over the period 1970 to 2010. And the spatialization of this rain was done using the krigging method using Geographic Information System (GIS) tools.

2.4.2. Frequency analysis of rainfall and extreme flows

Frequency analysis is used, in particular to estimate the magnitude of the temporal event XT with which a return period T is associated (quantile of return period T or probability of exceeding (p=1/T)). The XT estimate of the quantile value is obtained by adjusting a probability distribution F (x ;θ) to a sample of n observations x= {x1 ;... ;;xn}, where θ represents the parameter vector associated with the probability distribution F. The main steps of frequency analysis as described by Mélèdje[13]are :

2.4.2.1. Data selection

- Homogeneity (the data come from a homogeneous sample, so there is no significant difference in the average of sub-samples);
- Stationarity (no upward or downward trend in the data trend);
- Independence (no autocorrelation in series).

2.4.2.2. Checkingstationarity

The adjustment of a statistical distribution to the sample requires checking the stationarity of the data chronicle. This adjustment is made on the basis of an ordered sample for which an exceedance probability p or a non-exceedance probability q (q = 1-p) is calculated. Several empirical formulas exist to calculate the probability that ordered rains will not be exceeded. The one used in this study is the Cunnane formula already used by Soro[2]) and Mélèdje[13]:

$$q = \frac{k-q}{n-2q+1} \qquad \textit{Equation 1}$$

Where :
*k*is the rank of observations (ranked from lowest to highest) ;
*n*is the sample size ;
q=0,4(constant of the Cunnane formula).

Using the theoretical model provided by the adjusted statistical law, extrapolation is carried out to obtain the values of the quantiles (value of XT for a return period T). The relationship between the probability of not exceeding and the return period is :

$$T = \frac{1}{1-q} \qquad \textit{Equation 2}$$

2.4.2.3. Choosingstatisticalmodels

The choice of the different statistical models used to adjust the annual maximums (MAXAN) is based on theoretical considerations[9], [14]mentioned bySoro[2]. And the recommendations of previous work on this subject[2], [8], [15].The statistical models used a priori to adjust the variables of extreme daily rainfall are presented in Table 2 below.

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Table2 : Pre-selected statistical models for adjusting extreme rainfall and daily flows**.**

Sampling mode	Statistical model	Probabilitydensityfunction	Parameters
MAXAN	GEV-EV1 (Gumbel law)	*Equation 1* $f(x)=\frac{1}{\alpha}\exp\left[-\frac{x-u}{\alpha}-\exp\left(\frac{x-u}{\alpha}\right)\right]$	*α, u*
	GEV-EV2 (Fréchetlaw)	*Equation 2* $f(x)=\frac{1}{\alpha}\left(1-\frac{x-u}{\alpha}\right)\exp\left\{-\left[1-k(x-u)/\alpha\right]^{\frac{1}{k}}\right\}$	*α, u, k*
	GEV-EV3 (Weibulllaw)	*Equation 3* $f(x)=\frac{1}{\alpha}\left(1-\frac{x-u}{\alpha}\right)^{\frac{1}{k}-1}\exp\left\{1\left[1-k(x-u)/\alpha\right]^{\frac{1}{k}}\right\}$	*α, u, k*

2.4.2.4. Criteria for comparingprobabilitylaws

The purpose of these comparison criteria is to determine the statistical law that best adjusts the annual maxima taking into account the number of parameters (principle of parsimony)[2], [16]. For this study, two comparison criteria were used :Akaike information criteria (AIC) and Bayesian Information Criteria (BIC).

2.4.2.4.1. Akaike information criteria (AIC)

Akaike's information criteria[17]is based on a pseudo distance between a true unknown distribution (g), and an arbitrary distribution (f) set by θ. The Akaike Comparison Criterion (AIC) selects the model that achieves the best bias-variance trade-off for the number of N data available. The expression of the AIC criterion is defined as follows[18] :

$$AIC = -2ln(L) + 2k \qquad \textit{Equation 6}$$

With :*L*: the likelihood of the sample; *k*: number of parameters of the statistical law.

2.4.2.4.2. Bayesian Information Criteria (BIC)

The Bayesian Information Criteria[19]The Bayesian Information criterion is placed in a Bayesian context of selection of the statistical model. We are looking here for the statistical model (M_{BIC}) that maximizes the posterior distribution of the models, i.e. the most likely model based on the data. The Bayesian criterion is a minimization of the bias between the fitted model and the unknown true distribution[2].The expression of the Bayesian criterion is as follows[18] :

$$BIC = -2\,ln(L) + 2kln(N) \qquad \textit{Equation 7}$$

With *L* the likelihood of the sample ;*k* the number of parameters and *N* the sample size.

The best statistical model is the one with low AIC and BIC criteria values. [20].

3. Results and Discussion

3.1. Results

3.1.1. Rainfallparametersanalysis

3.1.1.1. Spatial analysis of rainfall in the Cavally River watershed

The spatial and temporalvariability analysis of the annual rainfall indices over the period 1970-2018 made it possible to place the Cavally catchment area in its spatial and temporal context (Figure 4). Rainfall in the north and south of the basin varies between 1611 mm and 1757 mm, while in the central part of the catchment area it varies between 1758 mm and 1970 mm. The results obtained show a heterogeneous distribution of rainfall intensities over the entire basin. It should be noted that the Cavally catchment area has a heterogeneous distribution but excess rainfall because rainfall amounts are above normal, which is about 1600 mm in western Côte d'Ivoire.

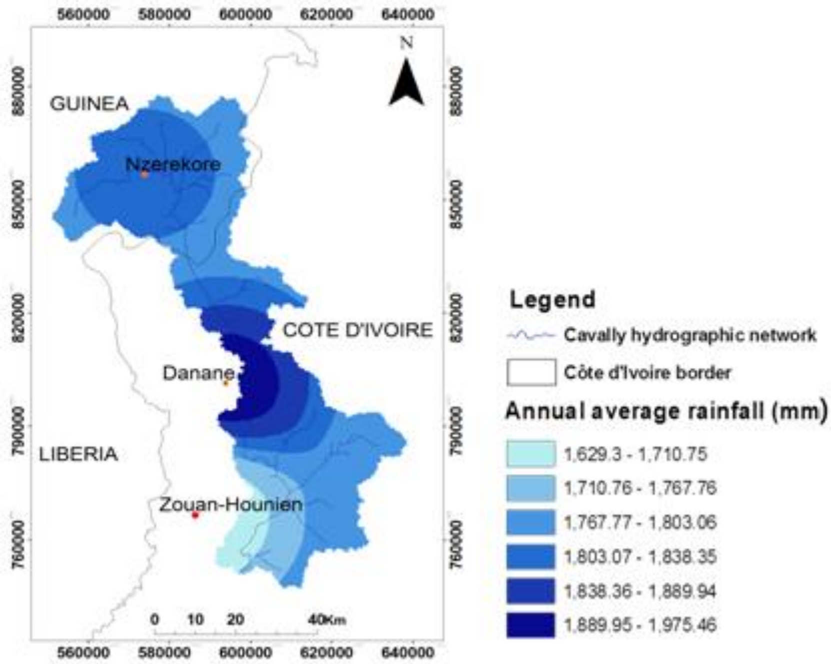

Figure 4 : Variation in the average annual rainfall amounts of the Cavally sub-basin from 1970 to 2018

3.1.1.2. Annualaveragerainfallcharacteristics

Table 3 presents the statistical characteristics of the annual rains at the Zouan-Hounien station. In the study area, annual rainfall varies from 997.8 mm to 1961.7 mm with an interannual average of 1535.9 mm..

Table 3: Annual precipitation characteristics at the Zouan-Hounien station.

Station	Period	Minimum	Average	Maximum	Standard deviation	Coefficient of variation
Zouan-Hounien	1970-2018	997,8	1535,9	1961,7	214,2	0,14

For the chronicle of the data used, it is the 3-parameter Weibull law that fits well with the maximum rainfall modules with low BIC and AIC criteria (Table 4).

Table 4: Statisticallawsapplied.

Statistical Law	Number of parameters	Comparison criteria		Rankings
		BIC	AIC	
Weibull	3	427,69	424,83	1
GEV	3	430,75	426,44	2
Gumbel	2	435,82	432,95	3

Table 5 presents the annual rainfall in dry and wet periods for different return periods.With regard to this table, Weibull's law fits better (Table 4) with the annual rainfall data series for both wet and dry periods. As an illustration, we observe 1970 mm of rain which corresponds to a rainfall of 100 years and 1560 mm corresponding to a rainfall of 2 years under Weibull's law.

Table 5 : Annual rainfall in dry and wet periods for various return periods.

Estimated annual rainfall according to return periods (mm)							
Return periods		100	50	20	10	5	2
Statistical laws	GEV	1970	1940	1880	1810	1730	1550
	Gumbel	2510	2340	2120	1950	1780	1510
	Weibull	1970	1930	1860	1800	1730	1560

3.1.1.3. Estimation of the quantiles of extreme rainfall

The experimental frequencies were determined using Hazen expression after ranking in ascending order (Figure 5). Return period rains of 2 years, 5 years, 10 years, 20 years, 50 years and 100 years were statistically estimated from available rainfall data. An illustration of the results of the graphical comparison criterion (Figure 5D) for the Ity station is presented in the graphs in Figure 5. According to the visual examination by the graphical method, the Weibull law (W2, A) has the advantage of being a simple model for the station of Ity whose annual daily rainfall values are well correlated to this law which shows good behaviour compared to the laws of Gumbel (EV1, B) and Gev (GEV, C) (Figures 5).

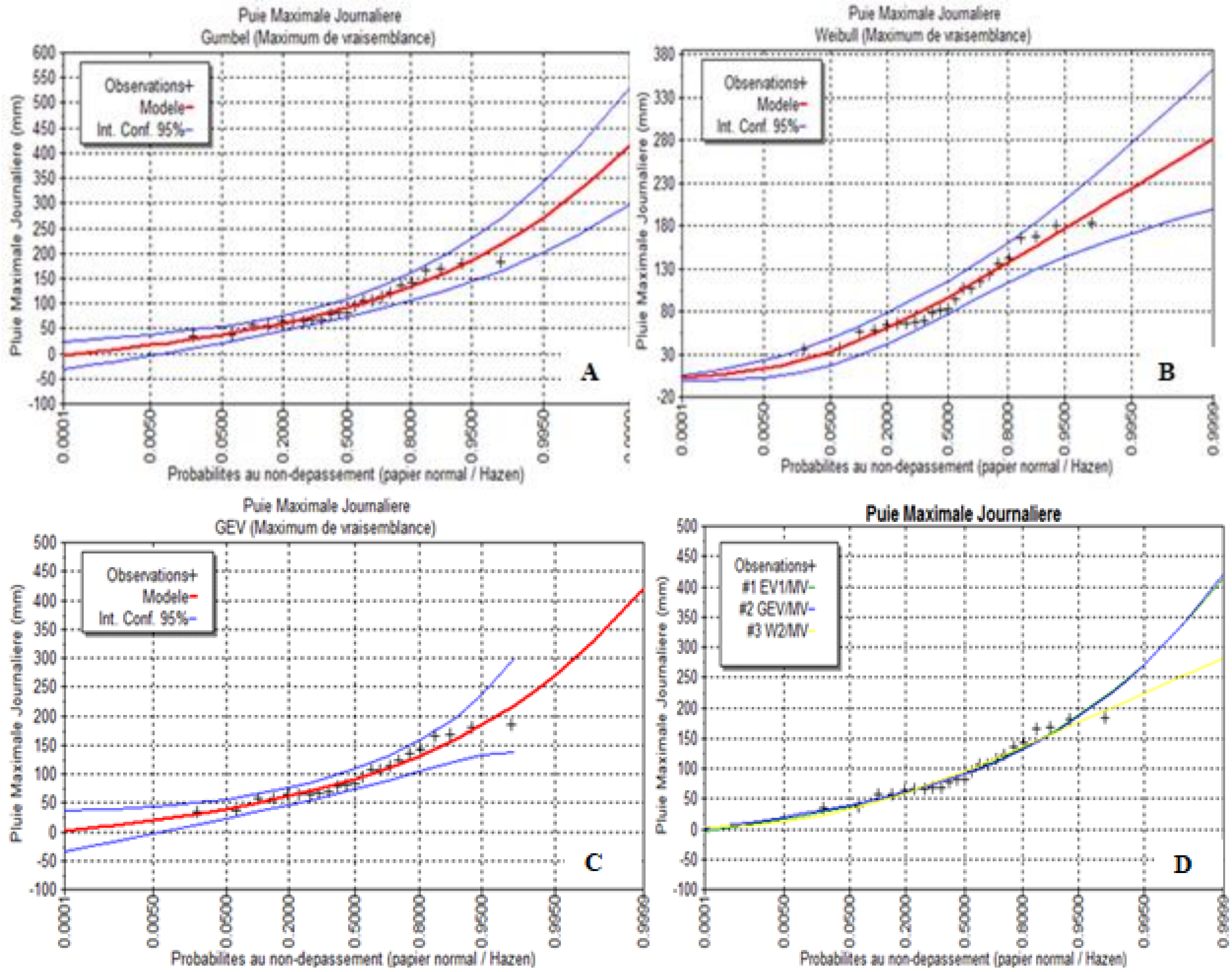

Figure 5: Adjusted Gumbel (A), Weibull (B) and GEV (C) laws and the graphical comparison criterion (D) by the maximum likelihood method to the Zouan-Hounien daily rainfall series

In the study area, daily rains of rare frequencies on an interannual scale were recorded on 12 August 1977 with a rainfall of 184 mm at the Zouan-Hounien station. The values of the return period quantiles of 2, 5, 10, 50 and 100 years were estimated using the maximum likelihood method for the period 1976 to 2000 expressed in mm (Table 6).

Table 6: Maximum daily rainfall (mm) from different return periods.

Rainfall station	Rainfall quantiles (mm)					
	2 years	5 years	10 years	20 years	50 years	100 years
Zouan-Hounien	91.2	133	160	187	221	246

3.1.2. Analysis of the hydrological frequency model

3.1.2.1. Choice of hydrological frequency model

Return period flows of 2 years, 5 years, 10 years, 20 years, 50 years and 100 years were statistically estimated from the available flow data. An illustration of the results of the graphical comparison criterion (Figure 6D) for the Ity station is presented in the graphs in Figure 6. According to the visual examination by the graphical method, the Weibull law (W2, A) has the advantage of being a simple model for the station of Ity whose values of the annual daily flows are well correlated to this law which shows a good behaviour compared to the laws of Gumbel (EV1, B) and Gev (GEV, C) (Figures 6).

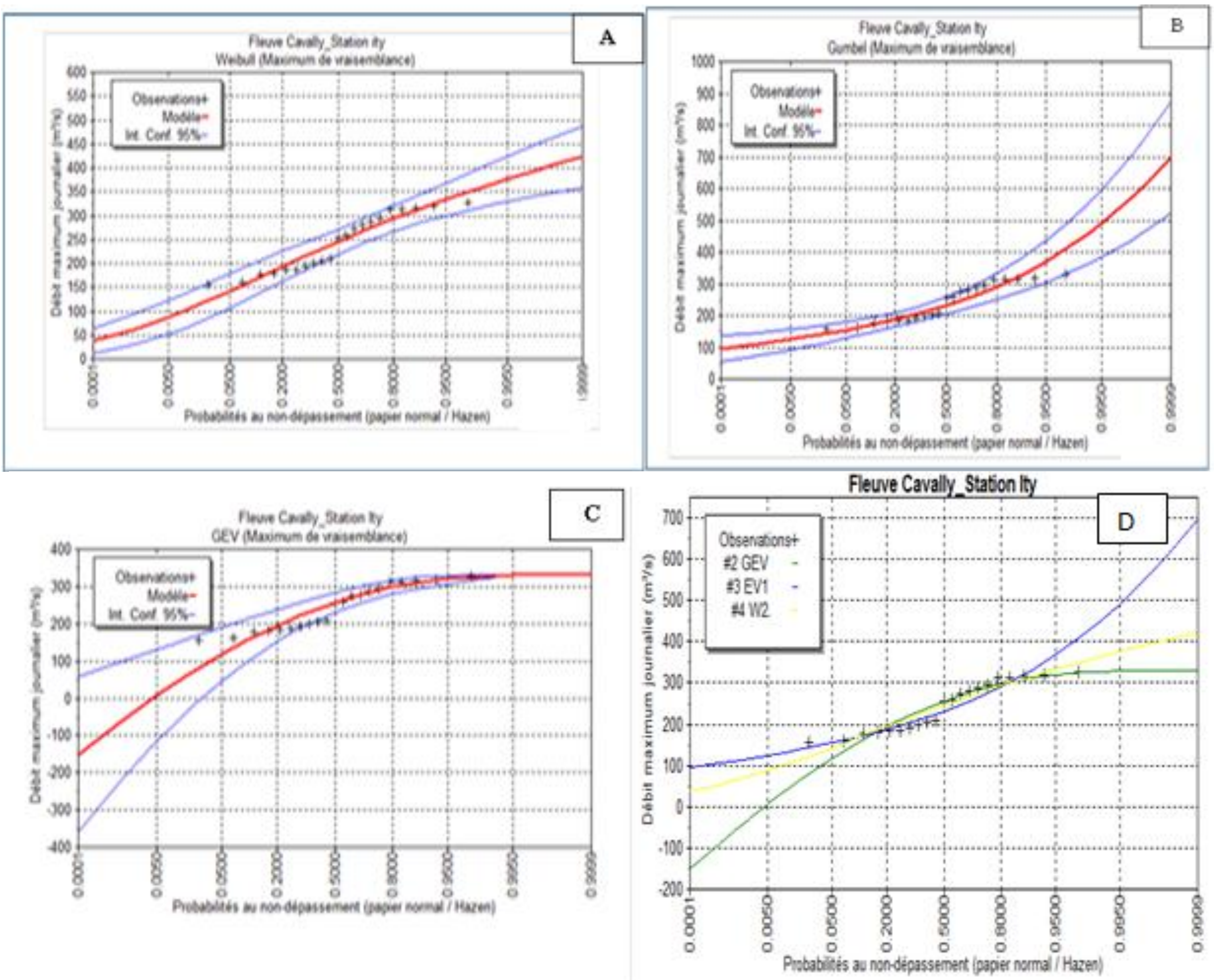

Figure 6 : Weibull's Laws (A), Gumbel's Laws (B) and GEV's Laws (C) adjusted and the graphical comparison criterion (D) by the maximum likelihood method to the annual average flow series of the Ity station

Table 7 presents the ranking of the competing laws. According to the comparison criteria, it is Weibull's law that fits well with the hydrological modules of the Cavally River, then comes Gumbel's law, followed by the GEV law. Hence the choice of Weibull's law for the frequency model of adjustment to the Cavally River modules.

Table 7: Comparison of statistical laws for the adjustment of modules from the Cavally River to the Ity station

Statistical Law	Nomber of parameters	comparison criteria		rankings
		BIC	AIC	
WEIBULL	3	236,145	234,056	1
GUMBEL	2	236,993	234,904	2
GEV	3	237,277	234,143	3

3.1.2.2. Different flood quantiles

Flood quantiles for various return periods are recorded in Table 8. Under Weibull's law, the flood quantiles of 100 and 2-year return periods are 365 and 246 m^3/s respectively. Only the quantiles of the return period of the best laws (retained) are presented.

Table 8: Flood quantiles and return flow periods at Ity station.

Return period (years)	Weibull (m^3/s)
100	365
50	353
20	334
10	316
5	293
2	246

3.1.3. Rain and flows for different return periods

The rain and flood quantiles for each return period are recorded in Table 9. For the purposes of this table, a centennial rainfall of 246 mm corresponds to a centennial flow of 365 m^3/s, for a return period of 2 years, a rainfall of 91.2 mm corresponds to a flood of 246 m^3/s.

Table 9: Rain and flood quantiles corresponding to the different return periods.

Return period (years)	Rain quantiles (mm)	Flood quantiles (m^3/s)
100	246	365
50	221	353
20	187	334
10	160	316
5	133	293
2	91,2	246

3.2 Discussion

The analysis of the spatial and temporal variability of the annual rainfall indices over the period 1970-2018 made it possible to increase the spatial and temporal distribution of the annual average rainfall in the Cavally catchment area. Indeed, rainfall in the north and south of the basin varies between 1611 mm and 1757 mm respectively, while in the central part of the catchment area it varies between 1758 mm and 1970 mm. It should be noted that the Cavally catchment area has a heterogeneous distribution but excess rainfall because rainfall amounts are above normal, which is about 1600 mm in western Côte d'Ivoire. This gradual increase is explained by the return to normal, hence the respect of rainfall in western Côte d'Ivoire, with a short dry season and a long rainy season. Moreover, due to its relatively large vegetation among that of Côte d'Ivoire, it contributes favourably to the rainfall balance, because rain and forest are undoubtedly linked since the more it rains, the more dense the natural vegetation is and vice versa. These results are corroborated byKouamé, Kouamé and Sorokoby*et al*. [21]–[23] on environmental changes that have occurred, including rainfall and changes in vegetation cover in recent decades. It is also supported by Kouamé [22]which states that the number of days in the rainy season had decreased throughout the western region of Côte d'Ivoire, but this decrease has so far increased quite sharply, just after the climatic break-up of the 1970s, which had a significant impact on rainfall. According toGoula*et al*.[8], Analysis of the average rainfall values between 1950 and 1998 reveals an inequality in the spatial distribution of rainfall in Côte d'Ivoire. A decrease in annual heights and the number of days of annual rainfall is observed, from the shoreline to the north, along a southwestern/northeastern axis (or gradient). This spatial distribution is explained by the continentalization effect, due to the impoverishment of the air mass carrying precipitation as it moves inland. Linked to the presence of predominant landforms in the west of the country, we note the existence of a second West-East axis of decline. Indeed, at equal latitude, the mountainous regions of the West receive more water levels (in the order of a few hundred millimetres) than those located in the East. This remark is also supported by the work of Boko et al.[24], which states that a decrease amounted to 4.6% in the 1980s.

In terms of frequency analysis, this study showed that Weibull's law fits better with the flood module of the Cavally River. Concerning the chronicle of rainfall data, the statistical analysis showed that the probability distribution of maximum daily annual rainfall follows Weibull's law with three (3) parameters.

These results are in line with those ofSoro[2], on the statistical modelling of extreme rainfall in Côte d'Ivoire showing that Weibull's law fits well with the rainfall data series in western Côte d'Ivoire. Therefore, for the chronicle of the data used, Weibull's law. However, the work of several authors recommends the use or combination of several parametric tests [4], [25]–[27] . However, the consistency and quality of the time series of rainfall and hydrological data could influence the results of frequency analysis through the choice of the statistical adjustment law. Indeed, several authors suggest that for a good frequency analysis, the chronicle of rainfall and hydrological data should be at least greater than 30 years [3], [10], [28].

An exceptional rainfall of 184 mm height corresponding almost to a 20-year rainfall quantile (187 mm) occurred on August 12, 1977.

4. Conclusion

The objective of this study is to analyze the occurrence of future extreme rainfall and hydrological events in the Cavally River watershed through local statistical models. This study also highlighted the statistical law that best fits the rainfall and hydrological modules of the Cavally River watershed. This is Weibull's law with three (3) parameters. It should also be recalled that the average interannual rainfall in the catchment area is 1535.9 ± 214.2 mm. Exceptional rainfall survived on August 12, 1977 with a height of 184 mm that could be qualified as a rainfall return period of 20 years since this rainfall quantile (20 years) is 187 mm. This study could serve as a basis for the design of hydraulic structures in the western region of Côte d'Ivoire.

References

[1] I. M. Bahari, I. Bouzou Moussa, and O. Faran Maiga, 'Évolution des caractéristiques pluviométriques et recrudescence des inondations dans les localités riveraines du fleuve Niger', *VertigO - la revue électronique en sciences de l'environnement*, May 2018.
[2] G. E. Soro, 'Modélisation statistique des pluies extrêmes en Côte d'Ivoire', Thèse de doctorat, Université Nangui Abrogoua, Abidjan, Côte d'Ivoire, 2011.
[3] G. Ragulina and T. Reitan, 'Generalized extreme value shape parameter and its nature for extreme precipitation using long time series and the Bayesian approach', *Hydrological Sciences Journal*, vol. 62, no. 6, pp. 863–879, Apr. 2017.
[4] T. A. Buishand, 'Extreme rainfall estimation by combining data from several sites', *Hydrological Sciences Journal*, vol. 36, no. 4, pp. 345–365, Aug. 1991.
[5] P. Calow and G. E. Petts, Eds., *The Rivers handbook: hydrological and ecological principles: in two volumes*. Oxford ; Boston: Blackwell Scientific Publications, 1992.
[6] K. Beven, J. Bathurst, E. O'connell, I. Littlewood, J. Blackie, and M. Robinson, 'Hydrological Modelling', *Progress in Modern Hydrology: Past, Present and Future*, Aug. 2015.
[7] J. O. Knighton and M. T. Walter, 'Critical rainfall statistics for predicting watershed flood responses: rethinking the design storm concept', *Hydrological Processes*, vol. 30, no. 21, pp. 3788–3803, Apr. 2016.
[8] B. T. A. Goula, B. Konan, Y. T. Brou, I. Savané, V. Fadika, and B. Srohourou, 'Estimation des pluies exceptionnelles journalières en zone tropicale: cas de la Côte d'Ivoire par comparaison des lois Lognormale et de Gumbel', *Journal des Sciences Hydrologiques*, vol. 52, no. 2, pp. 49–67, 2007.
[9] D. Koutsoyiannis, 'Statistics of extremes and estimation of extreme rainfall: I. Theoretical investigation /

Statistiques de valeurs extrêmes et estimation de précipitations extrêmes: I. Recherche théorique', *Hydrological Sciences Journal*, vol. 49, no. 4, p. null-590, Aug. 2004.

[10] S. Kusangaya, M. L. Warburton Toucher, and E. A. van Garderen, 'Evaluation of uncertainty in capturing the spatial variability and magnitudes of extreme hydrological events for the uMngeni catchment, South Africa', *Journal of Hydrology*, vol. 557, pp. 931–946, Feb. 2018.

[11] A. L. Brou, K. L. Kouassi, K. S. Konan, Z. A. Kouadio, K. K. Konan, and K. Bamory, 'Rain-Flow Modeling Using a Multi-Layer Artificial Neural Network on the Watershed of the Cavally River (Côte d'Ivoire)', *Journal of Water Resource and Protection*, vol. 09, no. 12, p. 1403, Nov. 2017.

[12] J. Tricart *et al.*, 'Une monographie physique de la Côte-d'Ivoire', in *Annales de Géographie*, 1973, vol. 82, pp. 369–372.

[13] N. H. Mélèdje, 'Modélisation de la dynamique hydrologique et du flux de sédiments dans le lac du barrage hydroélectrique d'Ayamé1', Doctorat unique, Université Nangui Abrogoua, Abidjan, Côte d'Ivoire, 2016.

[14] S. El Adlouni, B. Bobée, and T. B. M. J. Ouarda, 'On the tails of extreme event distributions in hydrology', *Journal of hydrology*, 2008.

[15] A. Muller, 'Comportement asymptotique de la distribution des pluies extrêmes en France.', Thèse de doctorat ès Science, Université de Montpellier II, France, 2006.

[16] M. M. Y. Lemay, 'Sur le principe de parcimonie dans l'ajustement des modèles ARMA', *Statistique et analyse des données*, vol. 14, no. 2, p. P. 81-95, 1989.

[17] H. Akaike, 'A new look at the statistical model identification', *IEEE Transactions on Automatic Control*, vol. 19, no. 6, pp. 716–723, Dec. 1974.

[18] E. Lebarbier and T. Mary-Huard, 'Le critère BIC : fondements théoriques et interprétation', INRIA, Research Report RR-5315, 2004.

[19] G. Schwarz, 'Estimating the Dimension of a Model', *The Annals of Statistics*, vol. 6, no. 2, pp. 461–464, 1978.

[20] H. Khaled and R. A. Ramachandro., 'Flood Frequency Analysis', *CRC Press*, 2001. [Online]. Available: https://www.crcpress.com/Flood-Frequency-Analysis/Hamed-Rao/p/book/9780849300837. [Accessed: 20-Sep-2018].

[21] K. F. Kouamé, 'Hydrogéologie des régions de montagne : apports des données de télédétection et des méthodes statistique et fractale à l'élaboration d'un système d'information hydrogéologique à référence spatiale des aquifères discontinus du secteur Man-Danané (Ouest de la Côte d'Ivoire)', Thèse de doctorat, Université de Cocody, Abidjan, Côte d'Ivoire, 1999.

[22] K. F. Kouamé, 'Influences de la variabilité climatique et de la dégradation environnementale sur le fonctionnement de l'hydrosystème du N'zo dans la région guinéenne humide et semi-montagneuse de la Côte d'Ivoire. Contribution de la télédétection, des Systèmes d'Informations Géographiques et du modèle hydrologique HYDROTEL', Doctorat ès Sciences Naturelles, Université de Cocody, Abidjan, Côte d'Ivoire, 2011.

[23] V. M. Sorokoby, M. B. Saley, K. F. Kouamé, E. M. V. Djagoua, K. Affian, and J. Biemi, 'Variabilité spatio-temporelle des paramètres climatiques et son incidence sur le tarissement dans les bassins versant de Bô et Débo (département de Soubré au Sud-Ouest de la Côte d'Ivoire)', *International Journal of Innovation and Applied Studies*, vol. 2, no. 3, pp. 287–299, 2013.

[24] K. A. N. N. Boko, G. Cissé, B. Koné, and D. Séri, 'Variabilité climatique et changements dans l'environnement à Korhogo en Côte D'ivoire : Mythes ou réalité ?', *European Scientific Journal*, vol. 12, no. 5, pp. 158–170, 2016.

[25] N. P. Fawthrop, 'Modelling Hydrological Processes for River Management', in *The Rivers Handbook*, P. Calow and G. E. Petts, Eds. Oxford, UK: Blackwell Science Ltd, 1994, pp. 187–212.

[26] K. S. Gbafa, S. Tiem, and K. Kokou, 'Intensity - duration - frequency curves and hydrological response of retention ponds in the city of Lome (Togo, West Africa)', *Research Journal of Engineering Sciences*, vol. 6, no. 11, pp. 7–19, 2017.

[27] L. A. N'Cho, A. Alla Della, and A. L. Brou, 'Frequency Analysis of the Bia River for preventive management of floods down the Ayame 1 Dam', *Baluki*, vol. II, no. 4, pp. 1–16, 2018.

[28] T. R. Marthews, E. M. Blyth, A. Martínez-de la Torre, and T. I. E. Veldkamp, 'A global scale evaluation of extreme events in the earth to observe project', *Hydrology and Earth System Sciences Discussions*, pp. 1–23, Jan. 2019.