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ANALYSIS OF CLIMATE CHANGE IMPACT ON THE STATISTICAL ADJUSTMENT MODELS OF EXTREME RAINFALL CASE OF IVORY COAST

ANALYSE DE L'IMPACT DES CHANGEMENTS CLIMATIQUES SUR LES LOIS STATISTIQUES D'AJUSTEMENT DES PLUIES EXTREMES CAS DE LA COTE D'IVOIRE

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ABSTRACT

The objective of this study is the analysis of the sensitivity of the statistical This study focuses on the analysis of the sensitivity of the statistical models of extremes according to the climatic context. It was based on annual maximum daily rainfall data and annual rainfall data collected over the period 1931-2010 from twenty-six (26) rainfall stations in Ivory Coast. The methodological approach is based on the one hand on the characterization of the climatic context based on annual rainfall. On the other hand, the approach of frequency analysis of extreme rainfall was adopted. The results of the climatic characterization highlighted two periods namely a wet period before 1970 (1931-2010) and a dry period after 1970 (1971-2010). It is found that the wet period is dominated by the models of Gumbel (54%), Gamma (19%) and exponential (11%). As for the dry period, it is dominated by the inverse Gamma (38%), Gumbel (35%) and Gamma (23%) models. The different statistical models of extremes are therefore sensitive to the climatic context of the data. These results raise the problem of hydrological norms calculated from the quantiles of the models of extremes in a current context of climate change.

Keywords: Climate change, Sensitivity of models, Statistical models of extremes, Frequency analysis, Ivory Coast.

RESUME

Cette étude porte sur l'analyse de la sensibilité des lois statistiques des extrêmes en fonction du contexte climatique. Elle s'est appuyée sur des données de pluies journalières maximales annuelles et des données de pluies annuelles collectées sur la période 1931-2010 à partir de vingt-six (26) stations pluviométriques en Côte d'Ivoire. La démarche méthodologique est basée d'une part sur la caractérisation du contexte climatique à partir de pluies annuelles D'autre part, la démarche de l'analyse fréquentielle des pluies extrêmes a été adoptée. Les résultats de la caractérisation climatique ont mis en évidence deux périodes à savoir une période humide avant 1970 (1931-2010) et une période sèche après 1970 (1971-2010). Il est constaté que la période humide est dominée par les lois de Gumbel (54%), Gamma (19%) et exponentielle (11%). Quant à la période sèche, elle est dominée par les lois Gamma inverse (38%), Gumbel (35%) et Gamma (23%). Les différentes lois statistiques des extrêmes sont donc sensibles au contexte climatique des données. Ces résultats posent le problème des normes hydrologiques calculées à partir des quantiles des lois des extrêmes dans un contexte actuel de changement climatique.

Mots clés : Changements climatiques, Sensibilité des lois, Analyse fréquentielle, Côte d'Ivoire.

INTRODUCTION

West Africa has been experiencing climate change phenomena since the 1970s and is one of the most vulnerable regions of the world (IPCC, 2013). These extreme events could amplify and become more frequent (Sarr et al., 2007 in Agoh, 2016). More than 80 to 90% of natural disasters are linked to hydro-climatic events such as droughts, heavy rains, floods (OMM, 2006). The work of the IPCC (2013) estimates that the concentration of CO_2 will double by 2100 while the average temperature in the coastal areas of West Africa (Senegal, Guinea Bissau) will increase by 3 °C and will be higher (4 °C) in the continental Sahel (Mali, Burkina Faso, Niger). This rise in temperature is already manifested by heavy rains and devastating floods in recent years. We can therefore expect, in the years to come, contrasting situations of alternating drought and excess rainfall. The consequence would be an increase in hydroclimatic disasters (Niasse et al., 2004 in Agoh, 2016). Also, many studies carried out on West African climate variability have shown that it is characterized by an alternation of dry periods and wet periods. 2016). Also, many studies carried out on West African climate variability have shown that it is characterized by an alternation of dry and wet periods. 2016). Also, many studies carried out on *West* African climate variability have shown that it is characterized by an alternation of dry and wet periods.

In Ivory Coast, it first affected the north, then gradually spread to the center and finally to the coast. These rainfall anomalies, observed for nearly five decades, have had an exceptional resonance in the northern and central regions. But the whole country has a significant vulnerability to rainfall deficits (Soro et al., 2010; Noufé, 2011; Soro, 2014, Traoré, 2016; Kouassi *et al.*, 2017). Goula et al. (2006). The resulting rainfall deficits range from 10% to 30% depending on the locality (Goula et al., 2006 in Agoh 2016). These studies have also shown a decrease in the number of rainy days (Kouassi et al., 2010). The rainy seasons have undergone modifications (Kouassi *et al*., 2010; Kouassi *et al*., 2018a). There is also the fact that climatic variability results in high intensity precipitation often causing flooding (Houndenou and Hernandez, 1998 in Agoh, 2016).

Thus, knowledge of extreme precipitation quantiles is necessary in the context of development projects for the design of structures hydraulic (water retention structures, anti-erosion structures, stormwater drainage networks, etc.) and in many engineering applications (Benkhaled, 2007; Kouassi *et al*., 2019). These quantiles are generally determined from extreme rainfall by means of statistical models called extremes. Statistical modeling of extreme values with maximum daily rainfall values is generally preferred to that of daily rainfall above a threshold, both by researchers and planners, because it is easier to apply and often statistically more effective (Habibi *et al*., 2013). Thus, several authors use the same variable of annual maximum daily rainfall to model extreme rainfall (Soro, 2011; Habibi *et al*., 2013; Koumassi *et al*., 2014; Agué and Afouda, 2015; Kouassi *et al*., 2018b). Frequency analysis is the most widely used statistical approach to quantify the risk associated with extreme rains (Goula et al., 2010; Soro, 2011; Habibi *and* al., 2013; Benabdesselam and Amarchi, 2013; Neppel *et al*., 2014; Kouassi *et al*., 2018b). The work of several authors (Goula *et al*., 2010; Soro, 2011; Habibi *et al*., 2013; Benabdesselam and Amarchi, 2013; NEPPEL *et al*., 2014; Kouassi *et al*., 2018b) yielded different results as to the choice of the best model. Indeed, the search for a model of the frequencies of the maximum daily rainfall heights is of great importance in operational hydrology: it constitutes the basis for calculating the design flood associated with a given probability of occurrence once the quantiles have been determined. (Sambou, 2004 in Kouassi *et al*, 2018b). Hence the need to analyze the sensitivity of statistical models of extremes regarding the climatic changes observed in progress.

The question that guides this research is the following: are the statistical models of extremes used to determine the quantiles of the annual maximum daily rainfall used for the sizing of hydraulic structures from the project flow rate sensitive to current climate changes in Ivory Coast?

The objective of this work is to analyze the sensitivity of the statistical models of extremes regarding the climatic context in Ivory Coast.

PRESENTATION OF THE STUDY AREA

Ivory Coast is in West Africa, in the intertropical zone, between the equator and the tropic of cancer, precisely between latitudes 4 ° 30 'and 10 ° 30' North and longitudes 8 ° 30 and 2 ° 30 West (Figure 1). It covers an area of 322,462 km^2 (about 1% of the African continent) and borders with the Gulf of Guinea to the south, Ghana to the east, Liberia and Guinea to the west, Mali, and Burkina Faso. Faso in the North. Figure 1 shows the study area which is Ivory Coast.

Figure 1: Presentation of the study area (Ivory Coast)

In Ivory Coast, there are four major climatic zones (Figure 2): the tropical transition regime or Sudanese climate in the north, the equatorial regime of attenuated transition or Baoulean climate in the center, the equatorial transition regime or the Attian climate in the South and the mountain regime or mountain climate in the West. Two main types of plant landscapes are present on Ivorian territory: a forest landscape and a savannah landscape. The first covers the southern half of the country and belongs to the Guinean domain. The second occupies the northern half of Ivory Coast and is part of the Sudanese domain (Brou, 2005). The Guinean domain has a predominantly dense humid forest vegetation. There are 4 sectors characterized by plant groups responding to different ecological conditions (Brou, 2005). Ivory Coast is characterized by a relief not high. Most of the land consists of trays and plains. The west of the country, mountainous region, however, presents some reliefs beyond a thousand meters (the mount Nimba culminates at 1,752 m). Aside from this region, altitudes generally vary between 100 and 500 meters, with most plateaus being around 300 to 400 meters. These have different aspects. The highest tops are rigid in their shapes as well as in their materials; those of intermediate levels quite often have blunt shapes; the lower ones have a certain rigidity but are made of loose materials. Huge and rigorously tabular and horizontal vertical expanses are sometimes present in the savanna regions, but also under the small snags of savannas included in the dense forest. The dominant element of these plates is constituted by a ferruginous armor visible on the surface in the form of rust-colored slabs, but sometimes veiled with sand.

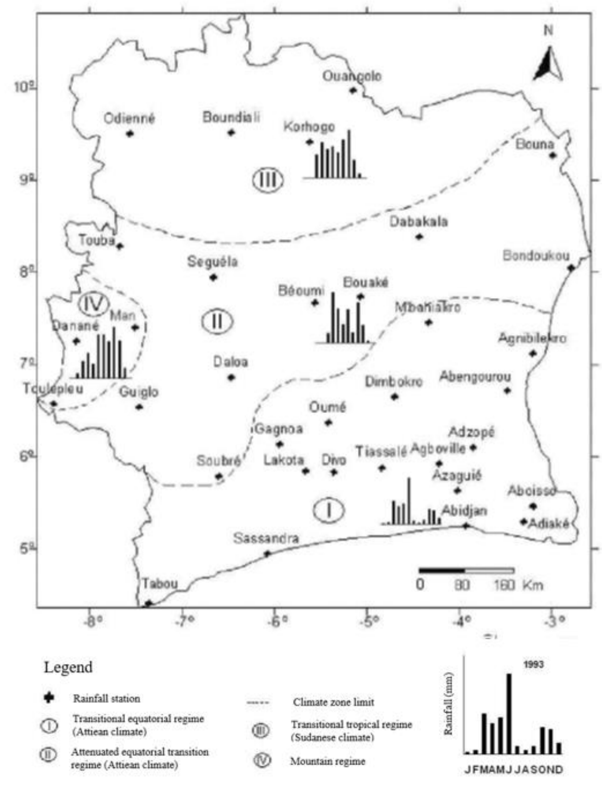

Figure 2: Main climatic zones of Ivory Coast (Goula *et al.*, 2007)

MATERIAL AND METHODS

Data

The data used to carry out this study come from the national network of meteorological measurements of Ivory Coast. The daily rainfall data used covers the period 1931-2010 and comes from twenty-six (26) rainfall stations distributed throughout the country (Figure 3). They were made available to us by SODEXAM (Aeronautical, Airport and Meteorological Development and Exploitation Company). These stations have been classified in the main climatic zones of Ivory Coast (Table 1). The choice of stations was guided by the availability and quality of the chronological data (fewer gaps with a threshold of 5%).

Table 1: Distribution of stations according to climatic zones

Zones Climatic	Weather	Stations
Zone I	Equatorial climate of transition	Abidjan, Aboisso, Agboville, Agnibilékro, Azaguie, Dimbokro, Gagnoa, Grand-Lahou, Lame, Tabou, Tiassalé, Sassandra
Zone II	Humid tropical climate	Bouaflé, Bouaké, Bouna, Dabakala, Daloa, Guiglo, Mankono, Séguéla
Zone III	Subtropical climate	Boundiali, Ferké, Odienné
Zone IV	Mountain climate	Man, Toulepleu

The various data were preprocessed. Indeed, the residue method was applied to the annual rainfall data to identify any erroneous values. The regional vector method and linear regression made it possible to fill in the gaps and correct the values identified as erroneous. Two types of series were formed such as the annual rainfall series and the annual maximum daily rainfall series. The statistical characteristics of the annual rains are given in Table 2. The analysis of Table 2 of the annual rainfall (1931 to 2010) shows that the average annual rainfall varies between 1184.89 mm (Agnibilekro) and 2300.44 mm (Tabou) with an average of 1484.55 mm. The variation coefficients fluctuate between 12.0% (Dabakala) and 28.2% (Grand Lahou) with an average of 19%. 92.3% of the series recorded coefficient of variation values lower than 25% against 7.7% which are higher (Boundiali and Grand Lahou). The series formed are therefore homogeneous overall except for that of Boundiali and Grand Lahou, which are heterogeneous.

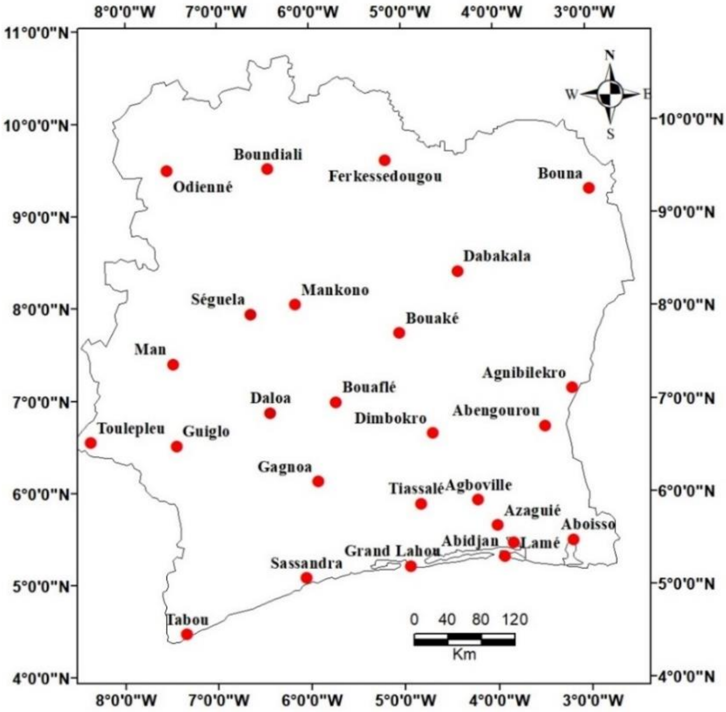

Figure 3: Location of the selected rainfall stations

Table 2: Statistical characteristics of annual rainfall amounts (1931-2010)

Stations	Average	Standard deviation	Coefficient of variation (%)	Asymmetry coefficient	Kurtosis coefficient
Abengourou	1344.68	237.42	17.7	0.74	0.45
Abidjan	1860.90	413.51	22.2	0.56	0.13
Aboisso	1795.34	410.85	22.9	0.47	0.00
Agboville	1384.54	254.58	18.4	0.44	-0.28
Agnibilekro	1184.89	216.61	18.3	0.41	0.04
Azaguié	1662.11	329.56	19.8	0.25	-0.64
Dimbokro	1225.99	199.73	16.3	1.95	5.61
Bouafle	1299.04	207.75	16, 0	0.95	1.38
Bouake	1614.28	384.92	23.8	1.03	0.67
Bouna	1238.76	158.04	12.8	1.69	5.23
Boundiali	1399.79	357.14	25.5	0.22	-0.23
Dabakala	1224.07	147.06	12.0	1.08	2.23
Daloa	1339.08	248.75	18.6	0.96	0.57
Ferké	1278.80	193.18	15.1	0.82	1.00
Gagnoa	1423.57	224.52	15.8	0.80	0.53

Grand Lahou	1582.85	446.74	28.2	0.57	0.39
Guiglo	1615.82	310.71	19.2	0.46	0.37
Lamé	1614.28	384.92	23.8	1.03	0.67
Man	1654.06	391.89	23.7	2.54	13.26
Mankono	1291.35	171.15	13.3	0.20	-0.13
Sassandra	1564.32	375.99	24.0	0.55	0.18
Seguela	1294.77	211.22	16.3	0.88	0.85
Odienné	1475.82	240.82	16.3	0.53	0.22
Tabou	2300.44	454.91	19.8	0.35	-0.02
Tiassalé	1265.96	274.38	21.7	0.04	0.72
Toulepleu	1662.76	370.25	22.3	0.31	-0.14

As for the asymmetry coefficients, they oscillate between 0.04 (Tiassalé) and 2.25 (Man) with an average of 0.76. Since the asymmetry coefficients are positive, the distribution is concentrated to the right of the mean. Also, the peak of the annual distribution is less flattened than that of a normal distribution because 76.92% of the flattening coefficients are positive against 24.08% which are negatives.

Table 3 presents the statistical characteristics of the annual maximum daily rainfall. The analysis of this table shows that the average extreme rainfall varies between 72.24 mm (Agnibilekro) and 142.15 mm (Tabou) with an average of 95.61 mm. The variation coefficients fluctuate between 27.22% (Dimbokro) and 57.77% (Boundiali) with an average of 39.65%. All the coefficients of variation are greater than 25%. This result reflects a dispersion of extreme rains considered over time. The series formed are therefore heterogeneous.

Table 3: Statistical characteristics of extreme rains (1931-2010)

Stations	**Average**	**Standard deviation**	**Coefficient of variation (%)**	**Asymmetry coefficient**	**Kurtosis coefficient**
Abengourou	84.12	38.64	45.93	1.73	3.56
Abidjan	139.24	45.74	32.85	0.80	1.75
Aboisso	130.37	57.05	43.76	1.18	1.38
Agboville	87.13	38.13	43.76	2.27	9.40
Agnibilekro	72.24	25.42	35.19	1.65	4.95
Azaguié	95.80	34.68	36.20	0.84	0.40
Dimbokro	82.44	31.00	37.61	1.33	2.98
Bouaflé	75.16	30.13	40.09	1.37	2.70
Bouaké	80.67	35.40	43.88	1.49	4.44
Bouna	82.62	30.59	37.03	5.07	34.55
Boundiali	91.20	52.69	57.77	1.26	2.11
Dabakala	86.36	32.51	37.64	0.43	0.23
Daloa	76.17	20.74	27.22	1.83	5.29
Ferké	76.76	30.63	39.91	0.78	0.86
Gagnoa	80.58	28.65	35.56	2.53	12.02
Grand Lahou	136.06	53.62	39.41	0.89	0.73
Guiglo	101.94	44.31	43.47	1.57	2.96
Lamé	126.66	44.41	35.06	1.54	2.98

Man	83.85	31.86	38.00	1.07	1.99
Mankono	85.62	31.48	36.76	0.46	-0.59
Sassandra	124.96	53.37	42.71	0.55	-0.45
Seguela	80.12	34.10	42.56	1.23	3.29
Odienné	83.24	29.14	35.01	0.21	-0.39
Tabou	88.11	35.13	39.88	1.74	3.76
Tiassalé	142.15	57.55	40.49	0.51	0.83
Toulepleu	92.27	39.86	43.20	2.27	7.12

The asymmetry coefficients range from 0.21 (Odienné) to 5.07 (Dabakala) with an average of 1.41. Since the asymmetry coefficients are positive, the distribution is concentrated to the right of the mean. As for the flattening coefficients, they oscillate between -0.59 (Mankono) and 34.55 (Dabakala) with an average of 4.19. 88.46% of the series recorded positive kurtosis coefficient values, so the peak of the annual maximum daily rainfall distribution is less flattened than that of a normal distribution.

Methods

Climate context analysis

The methodology consists first of making a hypothesis and verifying it from the Student test. Then, a determination of the variation deviations was made. Finally, the standardized pluviometric indices (SPI) were calculated over the study period from the annual rains.

Several authors have shown that in West Africa in general and in Ivory Coast in particular, the year 1970 is the year of rupture in most rainfall series (Kouasssi *et al*., 2010; Soro *et al*., 2011; Soro *et al*., 2016; Kouassi *et al*., 2017). From the above, an assumption was made according to which the year 1970 is the year of break in the annual rainfall data of the stations considered in the framework of this study. Thus, the verification of the existence of this break was made from the student test. This test was applied to the two sub-series of 40 years formed (1931-1970 and 1971-2010). In fact, the Student test or t test is a statistical test allowing the means of two groups of samples to be compared. It is therefore a question of knowing whether the means of the two groups are statistically significantly different. The adopted procedure consists of :

- Determine the value of the criterion t which is expressed as follows:

$$t = \frac{\bar{X}_a - \bar{X}_b}{\sqrt{S^2{}_{m(a)} - S^2{}_{m(b)}}} \quad (1)$$

Where:

Xa = sample mean (1931-1970).

Xb = sample mean (1971-2010).

Sm (a) = mean deviation of the sample (1931-1970).

Sm (b) = mean deviation of the sample (1971- 2010).

Determine t' the tabulated value of t from the Student table. We admit a confidence rate or probability of exceeding (p = 1-α) of 95% and a degree of freedom n' = n1 + n2 – 2.

Compare t and t'.

Conclude: if t (observed) < t' (theoretical t) then the difference between the means of the two samples is not statistically significant.

The variations in variation of the annual rainfall compared to the year 1970 chosen as the year of rupture were evaluated using the following formula:

$$D = \frac{x_j}{x_i} - 1 \quad (2)$$

Where:

D: variation deviation.

x_j : mean of the series after rupture.

x_i : average of the series before rupture.

Depending on the value of D, we have:

- If D ≥ 0, then there is a pluviometric excess of the period after the rupture compared to that before the rupture;

- If D < 0, then we speak of rainfall deficit of the period after the break compared to that before the break.

The analysis of annual rainfall trends was carried out using the standardized rainfall index (SPI) (Kouakou *et al*., 2012; Kouassi *et al*., 2017; Koné *et al*., 2019). This method was applied to the annual rains of the twenty-six stations over a period going from 1931 to 2010. The graphs relating to each station have been represented to highlight the different variations recorded.

The expression of SPI is as follows:

$$SPI = \frac{x_i - \bar{x}}{\sigma(x)} \quad (3)$$

With the series mean $\bar{x}$ and the series standard deviation $\sigma(x)$.

According to Soro *et al*. (2011) and Koné *et al*. (2019), depending on the value of the SPI, we have:

if the SPI < 0 *the period is considered dry.*

if the SPI > 0 *the period is considered wet.*

Statistical modeling of annual maximum daily rainfall

For the results of the frequency analysis to be validated, the data used must satisfy certain basic assumptions (El Adlouni *et al*., 2008; Kouassi *et al*.,2018b). Indeed, the data must be independent, homogeneous, and stationary. There are three (03) statistical tests to verify the assumptions of independence, stationarity, and homogeneity. These are the Kendall stationarity, Wald-Wolfowitz independence, and Wilcoxon homogeneity tests. In general, the determination of the best model of adjustment has always been delicate and the choice of the model can be crucial for the estimation of the precipitations of various periods of return of the extreme values in the hydrological studies for the sizing of the structures and the prediction of extreme events (flood, etc.). After the verification of these assumptions, the frequency analysis is carried out using several statistical tests (Jarque-Bera test, Log-Log graph, mean function of excess (FME), Hill's report and Jackson's statistic) (El Adlouni *et al*., 2008). Three main categories in which we can classify the ten distributions most used in hydrology, for the maximum values were distinguished by the decision support system (SAD) of the HYFRAN tool (table 4):

class C (regularly varying distribution): Fréchet (EV2), Halphen B Inverse (HIB), Log-Pearson type 3 (LP3), Gamma Inverse (GI);

class D (sub-exponential distributions): Halphen type A (HA), Halphen type B (HB), Gumbel (EV1), Pearson type 3 (P3), Gamma (G);

class E (exponential model).

Table 4: Statistical models retained for the adjustment of extreme rainfall.

Models of probability	Density functions f (x)	Settings
GEV model	$f(x) = \frac{1}{\alpha}\left[1 - \frac{k}{\alpha}(x-\mu)\right]^{\frac{1}{k}-1} . exp\left\{-\left[1 - \frac{k}{\alpha}(x-\mu)\right]^{\frac{1}{k}}\right\}$	μ, α, k **(4)**
Gumbel model	$f(x) = \frac{1}{\alpha} exp\left[-\frac{x-\mu}{\alpha} - \exp\left(-\frac{x-\mu}{\alpha}\right)\right]$	μ, α **(5)**
Normal model	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]$	μ, σ (6)
Lognormal model	$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} exp\left[-\frac{(lnx-\mu)^2}{2\sigma^2}\right]$	μ, σ (7)

Exponential model	$f(x) = \frac{1}{\alpha} exp\left[-\frac{x-m}{\alpha})\right]$	α, m (8)
Gamma model	$f(x) = \frac{\alpha^{\lambda}}{\Gamma(\lambda)} x^{\lambda-1} e^{-ax}$	α, λ, Γ (9)
Weibull model	$f(x) = \frac{1}{\alpha}(1 - \frac{x-\mu}{\alpha})^{\frac{1}{k}-1} \exp\{-\left[1 - k\left(\frac{x-\mu}{\alpha}\right)\right]^{\frac{1}{k}}\}$	μ, α, k (10)
Fréchet's model	$f(x) = \frac{1}{\alpha}(1 - \frac{x-\mu}{\alpha}) \exp\{-\left[1 - k\left(\frac{x-\mu}{\alpha}\right)\right]^{\frac{1}{k}}\}$	k, μ, α (11)
Pearson Model Type 3	$f(x) = \frac{\alpha^{\lambda}}{\Gamma(\lambda)} (x-m)^{\lambda-1} e^{-a(x-m)}$	α, λ, m (12)

Finally, an evaluation of the validity of the adopted models was carried out. For the estimation of the parameters of the statistical models, it is the maximum likelihood method that was retained because it has the advantage of being applicable to all the statistical distributions except for the Lognormal distribution 3 and Gamma which required the use of the method of moments (Laborde, 2000). Graphical representations and numerical criteria ($\chi 2$ test, BIC, and AIC criteria) were used for the choice of the best models (Soro *et al*., 2011; Kouassi *et al*., 2018b).

A comparative analysis of the models was carried out on the one hand over the two sub-periods (1931-1970 and 1971-2010) for a given station and on the other hand according to the main climatic zones defined in Ivory Coast. In each case, the frequency of occurrence of the best models was analyzed.

RESULTS AND DISCUSSION

Results of the climate context analysis

Verification of the hypothesis of existence of rupture

Student's statistical test was applied on the annual rainfall series for the periods 1931-1970 and 1971-2010 to confirm the hypothesis of the presence of rupture in 1970.The results are reported in Table IV. From the analysis of the table, it emerges that the Student test confirms in 81% of cases the existence of a break in 1970. Indeed, for these different stations, the difference between the two means of the two samples (before and after 1970) is statistically significant. Also, the experimental values which remain lower than the theoretical value are between 0.45 (Agnibilekro) and 1.17 (Dabakala). In 19% of the cases, the presence of a break in the annual rainfall series was not confirmed. The stations concerned are those of Abidjan, Agnibilekro, Dabakala, Mankono and Tabou. The experimental values which are greater than 1.91 are between 1.99 (Abengourou) and 5.81 (Sassandra).

Table 5: Results of the Student test applied to annual rainfall (1931-1970 and 1971-2010)

Stations	Criterion t	Criterion t '	Conclusion
Abengourou	1.99		presence of rupture
Abidjan	**1.44**		**absence of rupture**
Aboisso	2.36		presence of rupture
Agboville	2.97		presence of rupture
Agnibilekro	**0.45**		**absence of rupture**
Azaguie	3.27		presence of rupture
Dimbokro	2.12		presence of rupture
Bouaflé	2.65		presence of rupture
Bouaké	4.85		presence of rupture
Bouna	2.06		presence of rupture
Boundiali	3.77		presence of rupture
Dabakala	**1.17**		**absence of rupture**
Daloa	4.51		presence of rupture
Ferké	8.3	**1.91**	presence of rupture
Gagnoa	2.63		presence of rupture
Grand Lahou	2.17		presence of rupture
Guiglo	3.69		presence of rupture
Lamé	4.85		presence of rupture
Man	3.22		presence of rupture
Mankono	**1.77**		**absence of rupture**
Sassandra	5.81		presence of rupture
Seguela	3.45		presence of rupture
Odienné	4.41		presence of rupture
Tabou	**0.65**		**absence of rupture**
Tiassalé	3.66		presence of rupture
Toulepleu	3.51		presence of rupture

Annual rainfall variation

The variation deviations determined on either side of the year 1970 from the annual rains of the 26 stations are recorded. in table 6. The differences obtained are all negative, reflecting rainfall deficits going from the period 1931-1970 to the period 1971-2010. These deficits fluctuate between 1.81% (Agnibilekro) and 23.16% (Sassandra) with an average of 11.67. These results show that the period before 1970 (1931-1970) is wetter than the period after 1970 (1971-2010). In the equatorial climate of transition, the deficits fluctuate between 1.81% (Aboisso) and 23.16% (Abidjan) with an average of 10.81%. As for the humid tropical climate, it is characterized by deficits varying between 3.07% (Bouna) and 20.04% (Bouaké) with an average of 10.36%. The pluviometric deficits of the subtropical climate oscillate between 13.46% (Ferké) and 18.64% (Boundiali) with an average deficit of 16.71%. Regarding the mountain climate, its deficits vary between 14, 95% (Man) and 15.06% (Toulepleu) with an average of 14.85%. In general, the rainfall deficits decrease when leaving the South for the Center and from the North to the West.

Table 6 : Rainfall deficits at the various stations studied.

Stations	Average 1931-1970	Average 1971-2010	Deficit (%)
Abengourou	1396.37	1293.00	-7.40
Abidjan	1926.46	1795.34	-6.81
Aboisso	1900.20	1690.48	-11.04
Agboville	1464.85	1304.24	-10.96
Agnibilekro	1195.74	1174.04	-1.81
Azaguié	1775.25	1548.98	-12.75
Dimbokro	1272.16	1179.83	-7.26
Bouaflé	1357.96	1240.12	-8.68
Bouaké	1797.64	1430.92	-20.40
Bouna	1274.30	1203.22	-5.58
Boundiali	1538.54	1261.05	-18.04
Dabakala	1243.14	1205.01	-3.07
Daloa	1450.99	1227.18	-15.42
Ferké	1410.22	1147.39	-18.64
Gagnoa	1,487.01	1360.13	-8.53
Grand Lahou	1688.00	1477.70	-12.46
Guiglo	1734.34	1497.30	-13.67
Lamé	1797.64	1430.92	-20.40
Man	1786.71	1521.40	-14.85
Mankono	1324.53	1258.18	-5.01
Sassandra	1769.16	1359.48	-23.16
Seguela	1370.76	1218.78	-11.09
Odienné	1582.32	1369.33	-13.46
Tabou	2333.57	2267.31	-2.84
Tiassalé	1369.92	1162.00	-15.18
Toulepleu	1798.13	1527.39	-15.06

Trend analysis of annual rainfall series

Figures 4 illustrate the evolution of rainfall indices (SPI) for a few stations studied. Analysis of these figures shows that the rainfall trend can be split into two different periods. In general, the period before 1970 is characterized by positive rainfall indices and that after 1970 is marked by negative rainfall indices. These results obtained reflect a drop in rainfall after 1970.

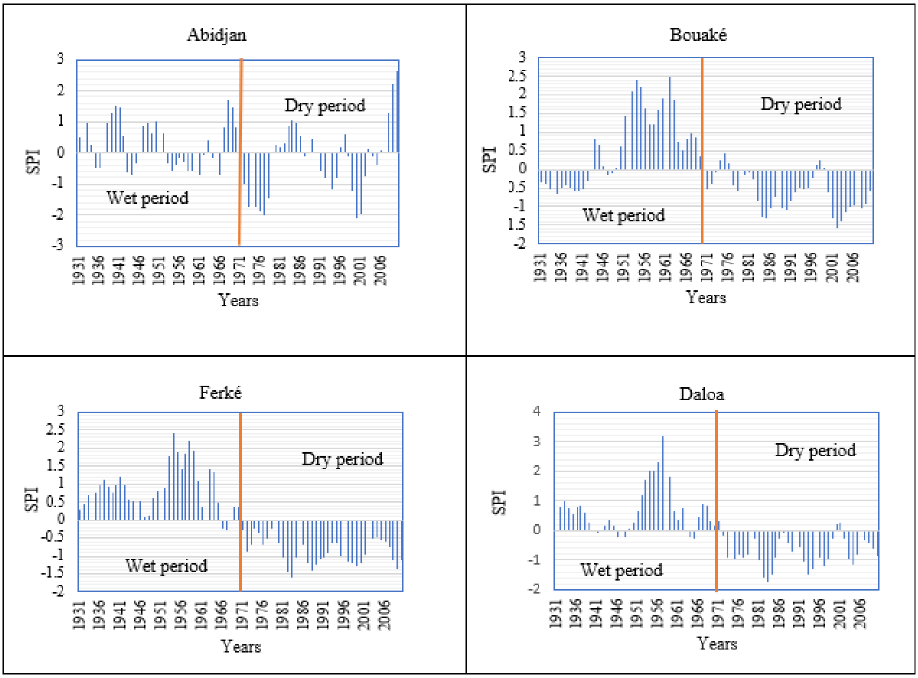

Figure 4: SPI of some stations studied (1931-2010)

The analysis of the results of the Student's test, of the variation deviations from 1970 and of the standard annual precipitation indices revealed two major periods with different climatic characteristics, namely a wet period before 1970 and a dry period after 1970. Thus, the subseries of the period 1931-1970 can be considered as belonging to a wet period. However, the subseries of the period 1971-2010 can be considered as belonging to a dry period.

RESULTS OF STATISTICAL MODELING OF EXTREME RAINFALL.

Verification of the application hypotheses of frequency analysis

Table 7 shows the results frequency analysis hypothesis tests. The analysis of this table made it possible to note that the independence and homogeneity tests remain valid for maximum daily rains at a threshold of 5% (rejection threshold of H0). As for the stationarity test of Kendall, it was accepted at the 1% threshold except for Odienné station.

Table 7: Results of the hypothesis tests of the frequency analysis

Stations	Independence test		Stationarity test		Homogeneity test	
	U	P	K	P	W	P
Abengourou	2,900	0.004	0.376	0.707	0.037	0.971
Abidjan	1,090	0.277	2,770	0.006	2,820	0.005
Aboisso	0.153	0.879	1,770	0.077	2,340	0.019
Agboville	0.005	0.996	1,810	0.070	2,200	0.028
Agnibilekro	2,880	0.004	0.655	0.512	0.418	0.676
Azaguié	0.358	0.720	2,520	0.012	2.100	0.036
Bouaflé	0.714	0.475	2,640	0.008	1,990	0.046
Bouaké	2.110	0.035	2,720	0.007	2,290	0.022
Bouna	2.110	0.035	0.795	0.427	0.093	0.926
Boundiali	1,960	0.054	2.180	0.029	0.865	0.387
Dabakala	0.832	0.406	1,170	0.240	0.836	0.403
Daloa	1,150	0.250	2,330	0.020	1,900	0.057
Dimbokro	0.800	0.005	0.028	0.978	0.406	0.685
Ferké	0.286	0.775	3,600	0.001	4,040	0.001
Gagnoa	2,460	0.014	0.028	0.978	0.840	0.401
Grand Lahou	0.880	0.379	0.624	0.533	1,360	0.174
Guiglo	0.844	0.399	0.366	0.714	0.999	0.318
Lamé	0.716	0.474	0.204	0.042	2,490	0.013
Man	3.060	0.002	2,230	0.026	0.901	0.367
Mankono	2,680	0.007	3.080	0.002	2,550	0.011
Odienné	3.930	0.058	4.350	0.001	3.310	0.001
Sassandra	2,490	0.013	4.710	0.001	4.220	0.001
Seguela	1,450	0.147	4,450	0.001	3.150	0.002
Tabou	3,960	0.000	3,860	0.001	2,460	0.014
Tiassalé	0.775	0.439	1,970	0.049	1,830	0.067
Toulepleu	0.715	0.475	1,390	0.165	0.418	0.676

These results show that the series of annual maximum precipitation values considered are made up of values independent, homogeneous, and stationary. Thus, the series of annual maximum daily rainfall verify the application conditions of frequency analysis.

RESULTS OF THE GRAPHICAL ADJUSTMENT OF THE MODELS TO EXTREME RAINFALL

From the analysis of the results from the decision support system (DSS), the most suitable classes are classes C, D and E for all the series of the study. Indeed, the wet series 1931-1970 has a CD tendency, ie 65.38%; while the dry series lends itself better to CE model classes with a probability of 73.07%. Thus, the adjustment was made from the five best models (model of Gumbel, Gamma model, exponential model, inverse Gamma model and Weibull model). The results of adjusting data for extreme rainfall over the different periods (1931-1970 and 1971-2010) show that the best models seem to be those of

Gumbel, Gamma, exponential, inverse Gamma and Weibull for the period 1931-1970 (Figure 5). On the other hand, for the period 1971-2010, the best models seem to be the inverse Gamma model, the Gumbel model, the Gamma model, and the Exponential model (Figure 6).

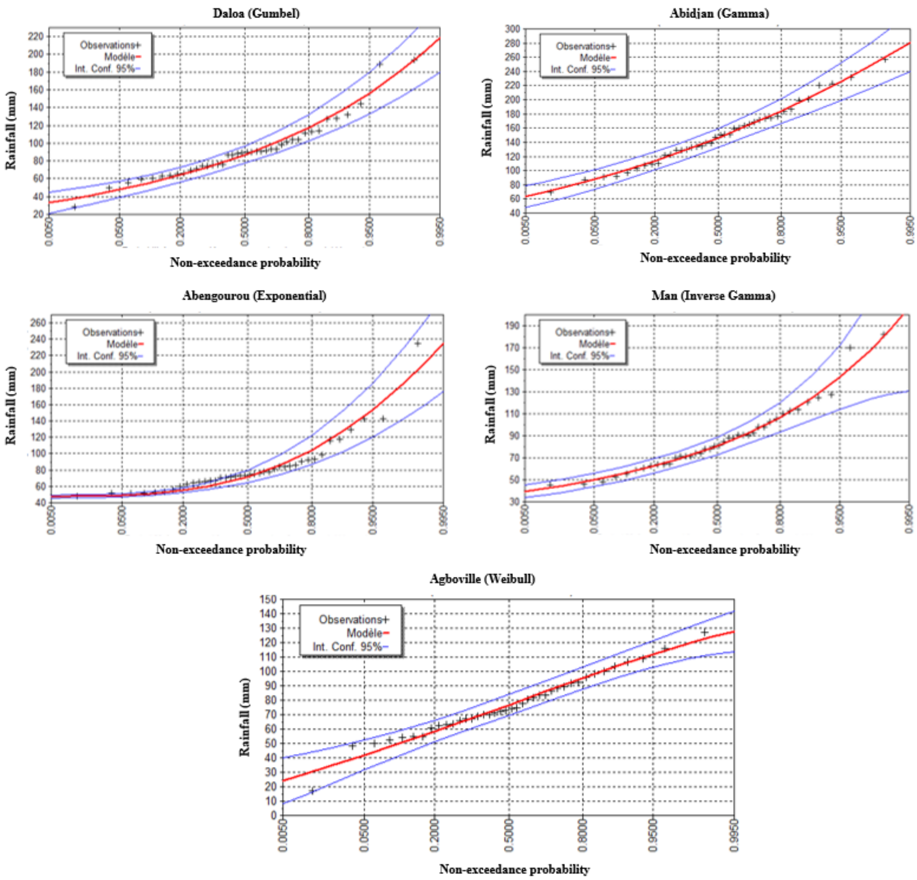

Figure 5: Adjustment of extreme rains to the five best models over the period 1931-1970

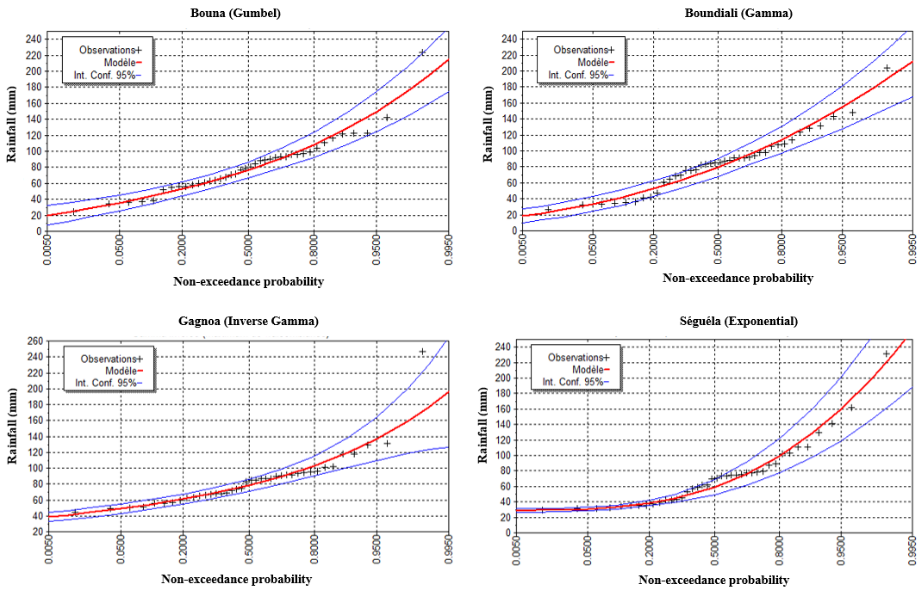

Figure 6: Adjustment of extreme rains to the four best models over the period 1971-2010

Chi-square test results

The results of the chi-square test applied to the annual maximum daily rainfall data are given in Tables 8 and 9. The goodness of fit is considered acceptable for the set of models which adjust the annual maximum daily rainfall to the significance level of 5%. The "chi-square" statistical fit test is accepted. The five models, such as Gumbel's model, the Gamma model, the inverse Gamma model, the Weibull model, and the exponential model, adjust the series of extreme rains of the period of 1931-1970. Regarding the series for the period 1971-2010, they are better adjusted by four models, namely the inverse Gamma model, the Gumbel model, the Gamma model, and the Exponential model.

Table 8: Results of the chi-square test over the period of 1931-1970

Stations	Model	Chi-square	P-Value
Abengourou	Exponential	9.6	0.09
Abidjan	Gamma	0.8	0.98
Aboisso	Gumbel	6.8	0.24
Agboville	GEV	3.2	0.52
Agnibilekro	Gumbel	2.8	0.73
Azaguié	Inverse gamma	5.6	0.35

Bouaflé	Inverse gamma	1.6	0.90
Bouaké	Exponential	3.6	0.61
Bouna	Gamma	2	0.85
Dabakala	Gumbel	4.4	0.49
Boundiali	GEV	5.2	0.27
Daloa	Gumbel	7.2	0.21
Dimbokro	Gumbel	3.2	0.67
Ferké	Gumbel	4.4	0.49
Gagnoa	Gumbel	2.4	0.79
Grand Lahou	Gumbel	8.8	0.12
Guiglo	Gumbel	2.4	0.79
Lamé	Gumbel	4.8	0.44
Man	Inverse gamma	0.8	0.98
Mankono	Gamma	4.8	0.44
Sassandra	Gamma	8.4	0.14
Seguela	Gumbel	3.2	0.67
Odienné	Gumbel	0.8	0.98
Tiassalé	Gamma	5.6	0.35
Tabou	Gumbel	6.8	0.24
Toulepleu	Gumbel	4.4	0.49

Table 9: Results of the chi-square test over the period 1971-2010

Stations	**Model**	**Chi-square**	**P-Value**
Abengourou	Inverse gamma	2.8	0.73
Abidjan	Gamma	9.2	0.10
Aboisso	Gumbel	0.8	0.98
Agboville	Gumbel	0.4	1.00
Agnibilekro	Gumbel	1.6	0.90
Azaguié	Gamma	5.2	0.39
Bouaflé	Inverse gamma	2.8	0.73
Bouaké	Inverse gamma	0.8	0.98
Bouna	Gumbel	2	0.85
Dabakala	Gumbel	7.2	0.21
Boundiali	Gamma	12	0.03
Daloa	Inverse gamma	7.6	0.18
Dimbokro	Gumbel	9.6	0.09
Ferké	Inverse gamma	1.6	0.90
Gagnoa	Inverse gamma	4.8	0.44
Grand Lahou	Gumbel	4	0.55

Guiglo	Gumbel	2	0.85
Lamé	Inverse gamma	6.4	0.27
Man	Gamma	10.4	0.06
Mankono	Gumbel	2.4	0.79
Sassandra	Inverse gamma	4.4	0.49
Seguela	Exponential	9.2	0.10
Odienné	Gamma	4	0.55
Tiassalé	Inverse gamma	8	0.16
Tabou	Gamma	13.6	0.02
Toulepleu	Inverse gamma	9.2	0.10

Numerical criteria AIC and BIC test results

The results of the AIC and BIC criteria have shown that on all twenty-six (26) stations, Gumbel's model is adjusted on fourteen (14) stations, i.e., 54%, on the other hand, the inverse Gamma and Weibull models are adjusted. each on two (02) stations, i.e., 8%. As for the Gamma and exponential models, they adjust respectively on 19% and 11% of the stations. Thus, Gumbel's model turns out to be the most appropriate for the adjustments of the maximum daily rainfall data for the wet period (1931-1970), followed respectively by the Gamma model, the exponential model, the inverse Gamma model and the GEV model. Regarding the dry period (1971-2010), the inverse Gamma model is best adjusted on ten (10) stations, i.e., 38%, Gumbel is adjusted on nine (09) stations, i.e., 35%, the Gamma model adjusts to five (05) or 23%. As for the Exponential model, it can only be adjusted on one (01) single station, i.e., 4%. Thus, the inverse Gamma model (38%) turns out to be the best suited for the adjustments of the maximum daily rainfall data of the dry subseries (1971-2010), followed by the Gumbel model (35%), the Gamma model (23%) and finally the Exponential model (4%). The analysis of the numerical criteria (AIC and BIC) shows a notable predominance of 54% of Gumbel's model (Class D) in the wet period 1931-1970 over the Gamma, Inverse Gamma, Weibull, and Exponential models (Figure 7). On the other hand, for the dry 1971-2010 series, a slight dominance of the Inverse Gamma model (Class C) is observed with a proportion of 38% over the Gumbel model (35%) (Figure 8). Whatever the series, Fréchet's model is not displayed.

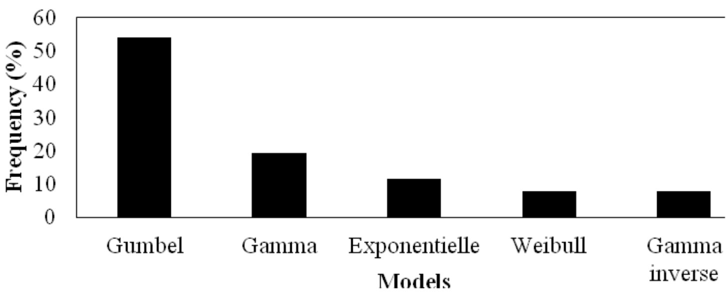

Figure 7: Frequencies of appearance of the best Models for wet period (1931-1970)

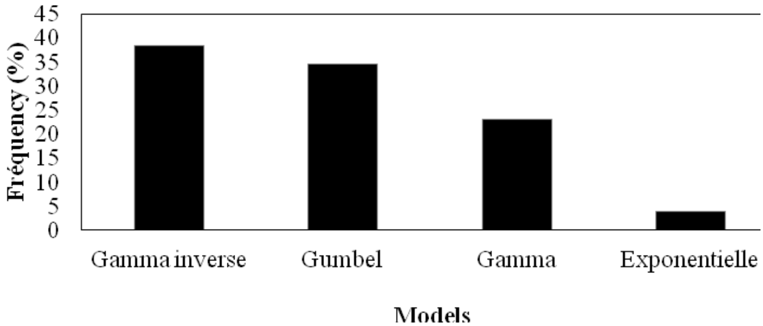

Figure 8: Frequencies of appearance of the best models during the dry period (1971-2010)

Models distribution according to climatic regimes

Concerning the wet period (1931-1970), in the equatorial climate of transition, the models which predominate are those of Gumbel with a proportion of appearance of 46.15% followed by the model Gamma (23.08%) and the exponential model (15, 38%). The inverse Gamma and Weibull models appear in last position with a percentage of 7.7% each. As for the humid tropical climate, it has the predominance of Gumbel's model (50%). The other models are presented respectively as follows: Gamma (25%), Exponential and Inverse Gamma with a proportion of 12.5% each. Regarding the subtropical climate, two thirds of the stations have a Gumbel tendency (66.67%). On the other hand, only a fringe (33.33%) is dominated by the Weibull model. As for the mountain climate, it is only dominated by Gumbel's model (100%).

Regarding the dry period, the equatorial climate of transition from the dry period is dominated respectively by the Gumbel (38.46%), inverse Gamma (30.77%), Gamma (23.08) and Exponential (7.7%). In the humid tropical climate, a predominance of Gumbel's model (50%) is observed, followed by the inverse Gamma model (37.5%) and Exponential (12.5%). The subtropical climate is predominated by the Gamma model (66.77%) followed by the inverse Gamma model (33.33%). Finally, the mountain climate presents an appearance in equal proportion of the Gamma (50%) and inverse Gamma (50%) models. The cross-analysis of these results shows that the Weibull model loses its representativeness in the dry period. Whatever the period, the equatorial climate of transition is dominated by the same models. As for the humid tropical climate, it also has the same models except for the Gamma model which appears only for the wet period. Regarding the subtropical climate and that of the mountains, the dominant models vary according to the period.

DISCUSSION

The hypothesis test (Student) carried out on the annual rainfall series confirmed the existence of a break in 1970 on 81% of the stations. In addition, the calculated deviations showed a drop in rainfall after the 1970s, so the period 1931-1970 is relatively wet than the period 1971-2010 which is dry. As for the rainfall deficits obtained, they are not homogeneous over the whole series (1931-2010). The lowest rainfall deficits were recorded in the south of the country (Abengourou, Abidjan, Agnibilekro, Dimbokro, Gagnoa and Tabou) with values between 1.8% 1 and 8.52%. On the other hand, the strongest were recorded in the North and in the Center (Bouaké, Ferké, Boundiali) with values between 18.04% and 20.40%. In general, the values of the rainfall deficits are between 1, 82% and 23.16%. The precipitation indices determined have confirmed that the year 1970 is the year of rupture. In view of all these analyzes, the year 1970 can be considered as a year of rupture in the Ivory Coast. A good agreement between the Student test and the methods applied (variation deviations and SPI) was demonstrated. Indeed, the rupture obtained in 1970 in this study agrees with several studies carried out in Ivory Coast (Kouassi *et al*., 2010; Soro *et al*., 2011; Soro *et al*., 2013, Kouassi *et al*., 2017). The variations in variation of the present study are lower than those obtained by Kouassi et al. (2017). Its values were between 15 and 30% in the watershed 1970 can be considered as a year of rupture in the Ivory Coast. A good agreement between the Student test and the methods applied (variation deviations and SPI) was demonstrated. Indeed, the rupture obtained in 1970 in this study agrees with several studies carried out in Ivory Coast (Kouassi *et al*., 2010; Soro *et al*., 2011; Soro *et al*., 2013, Kouassi *et al*., 2017). The variations in variation of the present study are lower than those obtained by Kouassi et al. (2017). Its values were between 15 and 30% in the watershed 1970 can be considered as a year of rupture in the Ivory Coast. A good agreement between the Student test and the methods applied (variation deviations and SPI) was demonstrated. Indeed, the rupture obtained in 1970 in this study agrees with several studies carried out in Ivory Coast (Kouassi *et al*., 2010; Soro *et al*., 2011; Soro *et al*., 2013, Kouassi *et al*., 2017). The variations in variation of the present study are lower than those obtained by Kouassi *et al*. (2017). Its values were between 15% and 30% in the watershed the rupture obtained in 1970 in this study agrees with several studies carried out in Ivory Coast (Kouassi *et al*., 2010; Soro *et al*., 2011; Soro *et al*., 2013, Kouassi *et al*., 2017). The variations in variation of the present study are lower than those obtained by Kouassi *et al*. (2017). Its values were between 15 and 30% in the watershed the rupture obtained in 1970 in this study agrees with several studies carried out in Ivory Coast (Kouassi *et al*., 2010; Soro *et al*., 2011; Soro *et al*., 2013, Kouassi *et al*., 2017). The variations in variation of the present study are lower than those obtained by Kouassi *et al*. (2017). Its values were between 15 and 30% in the watershed by Marahoué (Bandama). There is therefore a decrease in deficits and a resumption of rainfall in Ivory Coast.

The results of the tests prior to the frequency analysis indicate that the hypotheses of application to the frequency analysis are verified on all the series, except for the Odienné station. The series of annual maximum daily rainfall are therefore constituted by independent, homogeneous, and stationary values. This situation could be explained by the good quality of the data used. The frequency analysis carried out shows that it would be difficult to choose the best probability model graphically, hence the use of the comparison criteria (Chi-square test, AIC, and BIC criteria). The Chi-square test applied to the annual maximum daily rainfall shows that the Gumbel, inverse Gamma, Gamma, Weibull exponential were accepted at the 5% threshold, which confirms the results obtained by the graphical representations. Thus, the best model which best adjusts the maximum daily rains of the wet period (1931-1970) with a margin of error of 1% to 5% is Gumbel's model (54%) and is followed by the Gamma model (19%) and exponential (11%). Then come the inverse Gamma model and the Weibull model (8%) which are the least efficient. Moreover, for the second series, which is the dry period (1971-2010), the best suitable model is the inverse Gamma model (38%) followed by Gumbel's model (35%). Gamma model (23%) and exponential (4%) come in third and fourth position. This difference in models at the level of the two periods is explained by the fact that they do not have the same climatic characteristics.

Considering the twenty-six (26) series of maximum annual daily rainfall studied (1931-1970), 54% follow Gumbel's model. This clearly shows that the generalized model of type I extreme values (Gumbel's model) predominates in Ivory Coast but is not sufficient on its own in terms of quantifying the risk associated with extreme rains. Thus, for most stations (80%), the best models vary from the wet period to the dry period except for the Agnibilekro, Aboisso, Dabakala and Grand Lahou stations whose data are adjusted by the same model (Gumbel) and the Abidjan station which adjusts to the Gamma model regardless of the series. Overall, the models do not obey a climatic zone. In the coastal strip dominated by the equatorial transition regime, each statistical distribution has at least one area of validity. The same observation emerges in the center of Ivory Coast. The Gamma model, inverse Gamma and Gumbel apply better to the South and the Center, but also to the North and the West precisely in Boundiali, Man and Toulepleu. Statistical analysis revealed that no series of maximum daily rainfall studied can be compared to a realization of a Pearson model type III. The exponential model, although weakly represented, is nevertheless validated in the coverage area of the station of Abengourou, Bouaké Tabou and Séguéla. Among the different best models, some models are different from models already found in previous studies like the inverse Gamma model, the Gamma model, the Exponential model, and the Weibull model. This is due to the use of the DSS tool in this present study which proves to be rigorous regarding the classification of models. Indeed, it first showed the best classes, which made it possible to see the predominance of certain models which are not usual. Agué and Afouda (2015) have shown that the use of a model (Gumbel) could not allow a good estimate of the daily rainfall quantiles. These results align well with those of the present study. About the Abidjan station, certain authors such as Goula *et al*. (2010), Agué and Afouda (2015) concluded that the Gumbel model performed better than the Lognormal model. Goula et al. (2010) concluded, during their study of 47 Ivorian rainfall stations with maximum annual rainfall data covering the period 1947-1993, that Gumbel's model and the Lognormale model better adjust the maximum annual rainfall. For the same station in

Abidjan, Soro (2011) has shown through his study that the data from this station follow Gumbel's model. The difference in the results obtained for the same station could be justified by the difference between the study periods. However, a single conclusion is difficult to establish because the results differ according to the series studied (Muller, 2006). The distributions of models according to climatic zones are different from those obtained by Kamagaté (2015), whose studies were carried out on the that Gumbel's model and Lognormale model better adjust annual maximum rainfall. For the same station in Abidjan, Soro (2011) has shown through his study that the data from this station follow Gumbel's model. The difference in the results obtained for the same station could be justified by the difference between the study periods. However, a single conclusion is difficult to establish because the results differ according to the series studied (Muller, 2006). The distributions of models according to climatic zones are different from those obtained by Kamagaté (2015), whose studies were carried out on the that Gumbel's model and Lognormale model better adjust annual maximum rainfall. For the same station in Abidjan, Soro (2011) has shown through his study that the data from this station follow Gumbel's model. The difference in the results obtained for the same station could be justified by the difference between the study periods. However, a single conclusion is difficult to establish because the results differ according to the series studied (Muller, 2006). The distributions of models according to climatic zones are different from those obtained by Kamagaté (2015), whose studies were carried out on the difference in the results obtained for the same station could be justified by the difference between the study periods. However, a single conclusion is difficult to establish because the results differ according to the series studied (Muller, 2006). The distributions of models according to climatic zones are different from those obtained by Kamagaté (2015), whose studies were carried out on the difference in the results obtained for the same station could be justified by the difference between the study periods. However, a single conclusion is difficult to establish because the results differ according to the series studied (Muller, 2006). The distributions of models according to climatic zones are different from those obtained by Kamagaté (2015), whose studies were carried out on the period 1970-2010. For him, the Lognormale model applies well in the North. In addition, Hamzaoui (2016) carried out the statistical analysis of the maximum daily rainfall using the Decision Support System (DSS) and obtained the GEV model as the best model. Which is closer to our results because it is among the best models obtained in this study. For the same authors, the choice of the period of reference but above all the climatic context (wet period, dry period) therefore impacts the quantiles of annual maximum daily rainfall. This variation of the best models depending on the series is due to observed climate changes.

CONCLUSION

This study was devoted to the analysis of the sensitivity of the statistical models of extremes according to the climatic context of the series (wet period or dry period) in Côte d'Ivoire.

Analysis of the results of the Student test showed that the year 1970 can be considered as a break year for the different series of annual rainfall studied (81%) outside five stations (Abidjan, Agnibilekro, Dabakala, Mankono and Taboo). The evaluation of the variation deviations from 1970 showed that all the deviations show a deficit, reflecting a rainfall deficit. These deficits fluctuate between 1.81% (Agnibilékro) and 23.16% with an average of10.81%. The rainfall deficits decrease when leaving the South for the Center and from the North to the West. The standardized annual precipitation indices showed a predominance of positive SPI before 1970 and a predominance of negative SPI after 1970, therefore a drop in rainfall after 1970. In view of the various results, the period 1931-1970 can be considered as a wet period and the period 1971-2010 a dry period.

The results of the tests prior to the frequency analysis indicated that the assumptions of application to frequency analysis are verified on almost all series. Then, the series of the annual maximum daily rains are constituted by independent, homogeneous, and stationary values. The modeling of extreme rains from the statistical models obtained using the SAD system revealed the judicious adjustment of the Gumbel model (54%), the Gamma model (19%) and the Exponential model (11%) for the wet period (1931-1970). As for the dry period (1971-2010), it is dominated by the inverse Gamma model (38%), the Gumbel model (35%) and the Gamma model (23%). The analysis of the distribution of models according to climatic zones revealed three best models. Indeed, the equatorial climate of transition and the mountain climate are respectively dominated by the Gumbel model, the Gamma model, and the inverse Gamma model. Concerning the humid tropical climate and the subtropical climate, they are respectively dominated by the Gumbel model and the inverse Gamma model. At the end of these analyzes, the best models which best adjust the rainfall sub-series 1931-1970 and 1971-2010 are the Gumbel model, the Gamma model, and the inverse Gamma model. The statistical models of extremes are therefore sensitive to the climatic context of the series analyzed.

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