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Impacts of climate change on hydrological standards in West Africa: case of Ivory Coast

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Abstract

The objective of this study is to analyze the impacts of climate change on hydrological standards regarding rainfall norms (annual rains and extreme rains) and extreme rains quantiles in Ivory Coast. The study carried out was based on annual maximum daily rainfall data and annual rainfall data collected over the period 1931-2010 from twenty-six (26) rainfall stations. Firstly, the methodological approach is based on the evaluation of standards (normal and quantile) and on the other hand on their comparison from two periods with a different climatic context, such as a wet period (1931-1970) and a period dry (1971-2010). The comparison of the studied norms indicators (normal and quantile) was carried out using the matrices of the relative deviations and the binary matrices.

The main results show that the norms of the wet period are higher than those of the dry period. Analysis of binary matrices of annual rainfall normals shows that 100% of the values are greater than 1%. Regarding the normals of extreme rains, 96.15% are greater than 1%. The analysis of the binary matrices of the quantiles of the annual maximum daily rainfall revealed a rate of values greater than 1% varying between 88 and 100% regardless of the return period. We can confirm the impact of climate change on hydrology standards or norms in Ivory Coast. Therefore, we need to take account in the design of drainage facilities.

Key Words*:* Climate change, Hydrological standards, Stationarity, Ivory Coast.

Impacts des changements climatiques sur les normes hydrologiques en Afrique de l'Ouest : Cas de la Côte d'Ivoire

Résumé

L'objectif de cette étude est d'analyser les impacts du changement climatique sur les normes hydrologiques concernant les normes pluviométriques (pluies annuelles et pluies extrêmes) et les quantiles de pluies extrêmes en Côte d'Ivoire. L'étude réalisée s'est appuyée sur les données pluviométriques journalières maximales annuelles et les données pluviométriques annuelles collectées sur la période 1931-2010 à partir de vingt-six (26) stations pluviométriques. L'approche méthodologique s'appuie d'une part sur l'évaluation des normes (normales et quantiles) et d'autre part sur leur comparaison à partir de deux périodes au contexte climatique différent, comme une période humide (1931-1970) et une période sèche (1971 -2010). La comparaison des indicateurs de normes étudiés (normale et quantile) a été effectuée à l'aide des matrices des écarts relatifs et des matrices binaires.

Les principaux résultats montrent que les normes de la période humide sont supérieures à celles de la période sèche. L'analyse des matrices binaires des normales pluviométriques annuelles montre que 100% des valeurs sont supérieures à 1%. Concernant les normales des pluies extrêmes, 96,15% sont supérieures à 1%. L'analyse des matrices binaires des quantiles des précipitations journalières maximales annuelles a révélé un taux de valeurs supérieures à 1 % variant entre 88 et 100 % quelle que soit la période de retour. Nous pouvons confirmer l'impact du changement climatique sur les standards ou normes hydrologiques en Côte d'Ivoire. Par conséquent, nous devons en tenir compte dans la conception des installations de drainage.

Mots Clés : Changement climatique, Normes hydrologiques, Stationnarité, Côte d'Ivoire.

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INTRODUCTION

Like Africa in general and West Africa in particular, Ivory Coast has been experiencing climate change phenomena since the 1970s [1]. Despite this climatic context characterized by a rainfall deficit, many West African countries (Benin, Burkina Faso, Ivory Coast, Niger, Ghana, Senegal, Togo) are facing serious water problems flooding in both urban and rural areas [2]. According to [3], floods have been a major risk for the national territory of Ivory Coast in recent years (Abidjan, Bouaflé, Grand-Lahou, Dimbokro, M'bahiakro, etc.). The District of Abidjan is an example of cities that constantly experience floods, sometimes known as catastrophic (loss of life, disaster victims, injuries, house collapses, and many other significant damages to economic infrastructure) [3]. Studies carried out by [4] have shown that the rainfall deficit during the recent drought is largely offset by the modification of surface conditions (increase in cultivated areas and bare soils) in the functioning of watersheds. Paradoxically, this is how flow increases are observed in these basins despite the deficits recorded in rainfall. Also, for the construction of hydraulic structures, bridges, spillways for dams, heights of dikes to protect against floods, etc. we define the project flow rates in general fromextreme precipitation quantiles as precipitation is influenced by climate change [5]. This is the case of the empirical methods used which are based on the standards defined from the extreme rainfall quantiles (ORSTOM method, CRUPEDIX, SOCOSE method, etc.) on the one hand and standards based on annual and extreme rainfall norms (ORSTOM method, CIEH method, etc.) on the other. According to [6], the design of facilities does not consider interannual variability, which creates situations of scarcity in times of drought. This is the case of the Kossou dam in Ivory Coast, which was built during the end of the wet period, never reached its nominal capacity due to the persistence of the drought [7]. In short, the use of management and hydrological predetermination tools is made difficult by the climatic and environmental changes that West Africa has been experiencing since the 1970s [**5**]. The recent work of [**8**] Nassa (2017) on the evolution of the norms of the annual maximum daily rains in the District of Abidjan (South of Ivory Coast) over thirty-year sliding periods ranging from 1931 to 2020 using matrices absolute and binary relative deviations, showed a non-stationarity of the normals with regard to the impacts of climate change which affected the annual maximum daily rains at the Port-Bouët station (Abidjan, Ivory Coast). Likewise, [**3**] have highlighted a non-stationarity of the extreme rainfall quantiles of the Port-Bouët station (Abidjan, Ivory Coast) from the matrices of absolute and binary relative deviations. Thus, the matrix of relative deviations and the binary matrix remain help tools for designers showed a non-stationarity of the normals with regard to the impacts of climate change which affected the annual maximum daily rains at the Port-Bouët station (Abidjan, Ivory Coast). Likewise, [3] have highlighted a non-stationarity of the extreme rainfall quantiles of the Port-Bouët station (Abidjan, Ivory Coast) from the matrices of the absolute and binary relative deviations. Climate change has also affected weather patterns in Ivory Coast [9]. For the definition of climatic regimes, monthly and annual rainfall normals are generally defined.

We can therefore see that Hydrological standards are generally determined from rainfall data which is influenced by climate instability. The analysis of standards therefore requires the definition of reference periods considering this climatic instability. The adoption of a period of thirty years is a matter of tradition and the choice of this reference period confronts us with problems of representativeness [10]. To illustrate their point, the authors take as an example the thirty-year reference period 1961-1990. According to the authors, the very wet period of the early 1960s as well as the severe droughts that affected the Sahel during the 1968-1973 and 1981-1987 periods will significantly influence the averages calculated over the 1961-1990 period. The averages thus calculated mask the non-stationary nature of the rainfall. The authors believe that for a better representation of the climatic conditions that have prevailed since 1950, it is reasonable to split the time series of rainfall observations into two samples, one which would correspond to the wet phase prior to the onset of the decrease in rainfall, and the other in the dry phase that follows. [10] made predeterminations of the annual maximum daily mean flows from Niger to Koulikoro by splitting the total sample of observations into two parts, before and after 1970. The authors believe that for a better representation of the climatic conditions that have prevailed since 1950, it is reasonable to split the time series of rainfall observations into two samples, one which would correspond to the wet phase prior to the onset of the decrease in rainfall, and the other in the dry phase that follows. Thus, to limit the various hydroclimatic risks faced by Ivory Coast, a country in West Africa, it is essential to study the impact of climate change on hydrological standards. The main question guiding this research is the following: have the current climate changes impacted the hydrological standards defined from the rainfall norms (normal annual rainfall and normal extreme rainfall) and extreme rainfall quantiles in Ivory Coast?

The objective of this work is to analyze the impact of climate change on hydrological standards defined from rainfall norms (normal annual rainfall and normal extreme rainfall) and extreme rainfall quantiles in Ivory Coast.

MATERIALS AND METHODS

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 km² (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 [11]. The Guinean domain has a predominantly dense humid forest vegetation. 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). Apart 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.

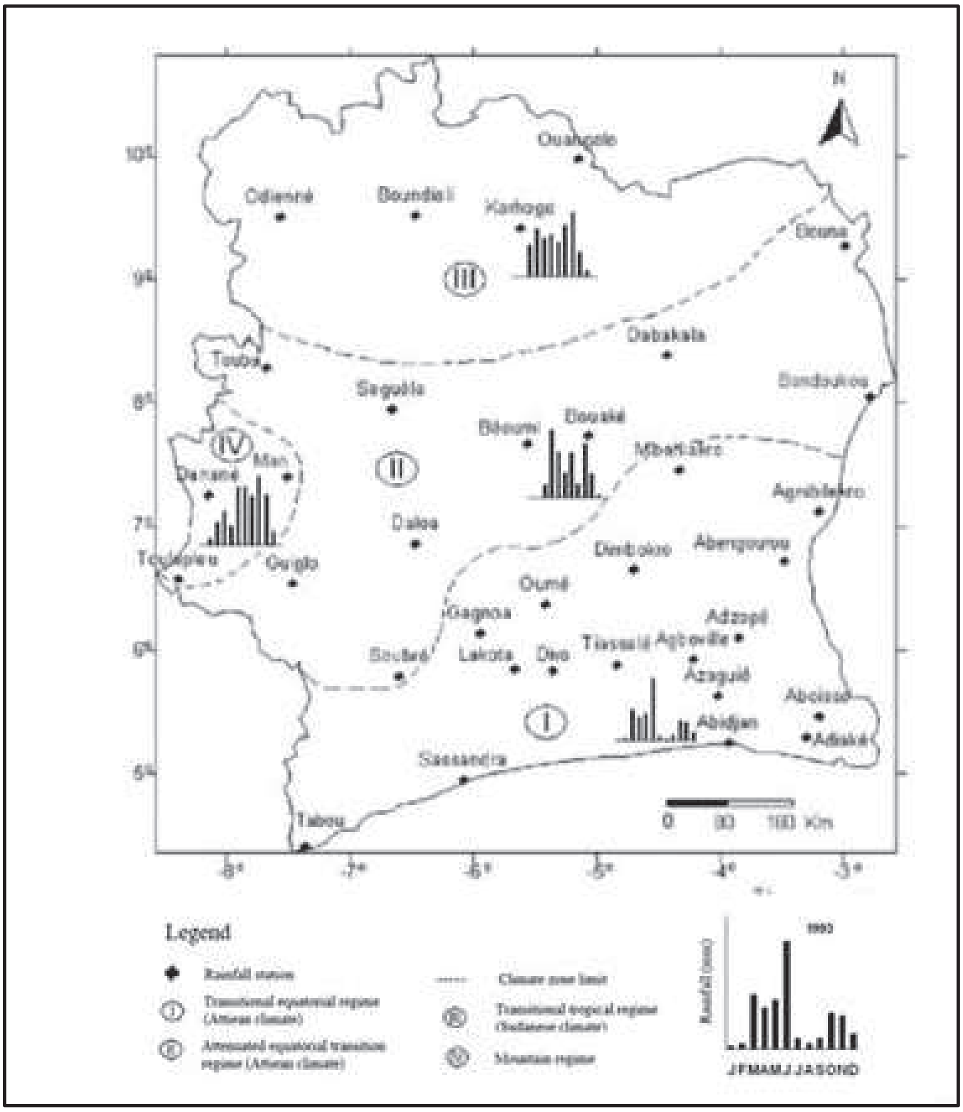

Figure 2 - Main climatic zones of Ivory Coast [**12**].

Data: The data used to carry out this study come from the national meteorological measurement network 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 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, Azaguié, Dimbokro, Gagnoa, Grand-Lahou, Lamé, Tabou, Tiassalé, Sassandra
Zone II	Humid tropical climate	Bouaflé, Bouaké, Bouna, Dabakala, Daloa, Guiglo, Mankono, Séguéla
Zone III	Subtropical climate	Boundiali, Ferkéssedougou, Odienné
Zone IV	Mountain climate	Man, Toulepleu

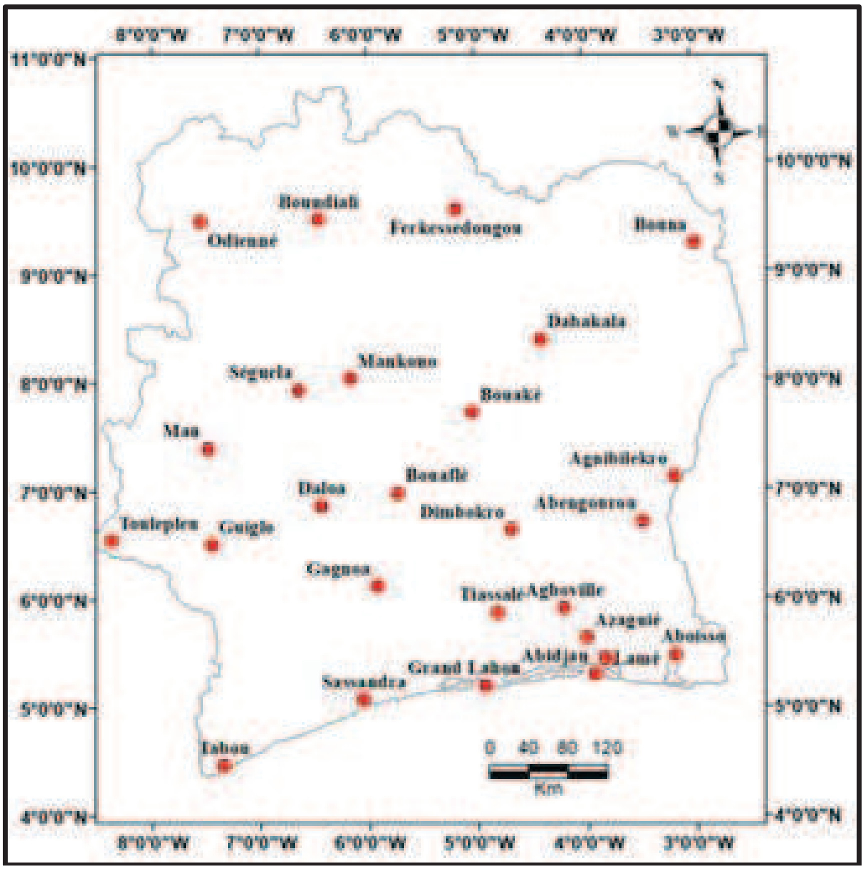

Figure 3 - Location of selected rainfall stations

The various data have undergone preprocessing. 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, namely the annual rainfall series and the annual maximum daily rainfall series. The statistical characteristics of the annual rains are given in Table 2.

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
Agnibilékro	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
Bouaflé	1299.04	207.75	16, 0	0.95	1.38
Bouaké	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
Ferkéssédougou	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
Séguéla	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

The analysis of table 2 of the annual rainfall heights (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. This result reflects a very low dispersion of the annual rainfall levels of the series considered over time. 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 is negative.

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

Stations	Average (mm)	Standard deviation (mm)	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
Agnibilékro	72.24	25.42	35.19	1.65	4.95
Azaguié	95.80	34.68	36.20	0.84	0.40
Bouaflé	82.44	31.00	37.61	1.33	2.98
Bouaké	75.16	30.13	40.09	1.37	2.70
Bouna	80.67	35.40	43.88	1.49	4.44
Dabakala	82.62	30.59	37.03	5.07	34.55
Boundiali	91.20	52.69	57.77	1.26	2.11
Daloa	86.36	32.51	37.64	0.43	0.23
Dimbokro	76.17	20.74	27.22	1.83	5.29
Ferkessédougou	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
Séguéla	80.12	34.10	42.56	1.23	3.29
Odienné	83.24	29.14	35.01	0.21	-0.39
Tiassalé	88.11	35.13	39.88	1.74	3.76
Tabou	142.15	57.55	40.49	0.51	0.83
Toulepleu	92.27	39.86	43.20	2.27	7.12

Analysis of the table 3 shows that the average extreme rains vary between 72.24 mm (Agnibilekro) and 142.15 mm (Tabou) with an average of 95.61 mm. The coefficients of variation fluctuate between 27.22% (Dimbokro) and 57.77% (Boundiali) with an average of 39.65%. All coefficients of variation are greater than 25%. This result reflects a dispersion of the extreme rains considered over time. The series formed are therefore heterogeneous. 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.

Approach to the analysis of hydrological standards indicators

Methods of calculating hydrological standards

The comparative analysis of standards was based on the principle that the concept of hydrological standards refers to a stable climate ([7]; [10]). The standard indicators defined during this study are the normals and the quantiles of extreme rainfall. These data are not only scientifically interesting, but also serve as a planning basis for the authorities and various economic sectors (construction, agriculture, energy, tourism, etc.).

The annual rainfall normals and those of the annual maximum daily rainfall were calculated using the average ([6]; [13]) and over the 1931-1970 and 1971-2010 sub-periods. The mean is the simplest statistical quantity and the most used for the calculation of normals. It makes it possible to reduce a whole sample of values to one. This is the main feature that serves as the starting point for most standards. Indeed, the work of [14] has shown that the period 1931-1970 is wet and that the period 1971-2010 is dry.

The standards defined from the quantiles of annual maximum daily rainfall were calculated over the 1931-1970 and 1971-2010 sub-periods. The statistical modeling of annual maximum daily rainfall carried out by [14] on the same stations used during this work and from the same data by means of several laws of extremes over the two sub-periods (1931-1970 and 1971- 2010) showed that the wet period (1931-1970) is dominated by the laws of Gumbel (54%), Gamma (19%) and exponential (11%). As for the dry period (1971-2010), it is dominated by the inverse Gamma (38%), Gumbel (35%) and Gamma (23%) laws. At the level of the wet period (1931-1970), in the equatorial climate of transition, the laws which predominate are those of Gumbel (46.15%), Gamma (23.08%) and Exponential (15.38%). In the humid tropical climate, we have the predominance of the laws of Gumbel (50%) and Gamma (25%). 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 law. As for the mountain climate, it is only dominated by Gumbel's law (100%). With regard to the dry period, the equatorial climate of transition from the dry period is dominated respectively by the laws Gumbel (38.46%), Gamma inverse (30.77%) and Gamma (23.08%). In the humid tropical climate, a predominance of the laws of Gumbel (50%) and inverse Gamma (37.5%) is observed. As for the subtropical climate, it is predominated by the Gamma law (66.77%) followed by the inverse Gamma law (33.33%). Finally, the mountain climate presents an appearance in equal proportion of the Gamma (50%) and inverse Gamma (50%) laws.

The quantiles were determined from the best statistical models that best fit the annual maximum daily rainfall data from the twenty-six (26) stations selected over the two sub-periods (1931-1970 and 1971-2010) [**14**]. The determination of the quantiles of the annual maximum daily rainfall was carried out using the analytical approach, the mathematical basis of which is as follows [**3**]:

$$x(F) = x_0 + S \times u(F) \quad \textbf{(1)}$$

Where :

- x_0 : the arithmetic mean ;
- S : the standard deviation of the sample considered ;
- *u* : reduced variable of the considered law.

x_0 et S being know, we compute x(F), which is the desired quantile for a given non-exceeding frequency F_i.

After having determined the quantile relative to a given frequency, it is necessary to know the confidence interval of this quantile, that is to say the range of values which should contain this quantile. Thus, the quantiles of the annual maximum daily rainfall were calculated over the periods 1931-1970 and 1971-2010 for several return durations (T: 2, 5, 10, 20, 50 and 100 years) [**3**]. The estimation of quantiles for the sizing of hydraulic structures requires a certain level of confidence. Indeed, the statistical models used to represent extreme rains are tainted with errors that need to be clarified.

Procedure for comparing hydrological standards

The absolute relative deviations between the standards studied (annual rainfall norms, extreme rainfall norms and extreme rainfall quantiles) considering each time, a standard as a reference value were evaluated. The absolute relative deviations represent the absolute value of the difference between the considered standard and the reference standard. The absolute relative deviations are expressed as a percentage and are presented as follows ([**3**]; [**6**]):

$$\Delta X_{i/réf} = 100 \times \left| \frac{X_i - X_{réf}}{X_{réf}} \right| \quad \textbf{(2)}$$

Where:

- $\Delta X_{i/réf}$ **:** absolute relative deviation.
- X_i **:** norm of period i.
- $X_{réf}$ **:** reference norm.
- i: period (year).

An acceptability threshold of 1% was retained, i.e., if the absolute relative deviation is less than or equal to 1%, it is considered that the difference between the standard considered, and the reference standard is not statistically significant. The set of absolute relative deviations made it possible to constitute the matrices of absolute relative deviations. These matrices have been transformed into binary matrices (0,1). In fact, deviations less than 1%

have been replaced by 1 while deviations greater than 1% have been replaced by 0. The "1" reflects a non-significant difference between the standards while the "0" reflects a significant difference between standards.

RESULTS AND DISCUSSION

Standards analysis

Analysis of annual rainfall norms

The statistical characteristics of the extreme rainfall norms calculated over the various periods 1931-1971 and 1971-2010 are given in Table 4.

Analysis of the table 4 shows that the normal values oscillate between 1195.74 and 2333.57 mm with an average of 1556.75 mm for the sub-period 1931-1970. As for the period 1971-2010, the values vary between 1147.39 and 2267.31 mm with an average of 1368.39 mm. The normal for the period 1931-1970 is higher than the normal for the period 1971-2010. The statistical characteristics (minimum, maximum and average) of the annual rainfall normals of the wet period (1931-1970) remain higher than those of the dry period (1971-2010).

Table 4 : Normal annual rainfall (1931-2010)

Stations	Normal (mm) 1931-1970	Normal (mm) 1971-2010
Abengourou	1396.37	1293.0
Abidjan	1926.46	1795.34
Aboisso	1900.20	1690.48
Agboville	1464.85	1304.24
Agnibilékro	1195.74	1174.04
Azaguié	1775.25	1548.98
Dimbokro	1272.16	1179.83
Bouaflé	1357.96	1240.12
Bouaké	1797.64	1430.92
Bouna	1274.30	1203.22
Boundiali	1538.54	1261.05
Dabakala	1243.14	1205.01
Daloa	1450.99	1227.18
Ferkéssédougou	1410.22	1147.39
Gagnoa	1,487.01	1360.13
Grand Lahou	1688.0	1477.70
Guiglo	1734.34	1497.3
Lamé	1797.64	1430.92
Man	1786.71	1521.4
Mankono	1324.53	1258.18
Sassandra	1769.16	1359.48
Séguéla	1370.76	1218.78
Odienné	1582.32	1369.33
Tabou	2333.57	2267.31
Tiassalé	1369.92	1162.0
Toulepleu	1798.13	1527.39
Minimum	1195.74	1147.39
Maximum	2333.57	2267.31
Average	1556.75	1368.39

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Analysis of extreme rainfall norms

Table 5 presents the normals for the extreme rains of the wet period (1931-1970) and of the dry period (1971-2010).

Table 5 : Normal extreme rains (1931-2010)

Stations	Normal (mm) 1931-1970	Normal (mm) 1971-2010
Abengourou	79.06	85.45
Abidjan	152.67	128.73
Aboisso	114.37	140.87
Agboville	73.70	97.61
Agnibilékro	72.35	71.63
Azaguié	91.40	103.97
Bouaflé	85.60	81.46
Bouaké	77.46	71.57
Bouna	72.29	85.88
Boundiali	88.54	84.67
Dabakala	82.75	79.40
Daloa	93.99	80.73
Dimbokro	73.10	77.27
Ferkéssédougou	89.53	66.06
Gagnoa	73.84	84.27
Grand Lahou	149.70	127.57
Guiglo	87.11	113.22
Lamé	133.82	120.09
Man	82.54	81.08
Mankono	93.89	79.19
Odienné	91.48	72.65
Sassandra	146.11	104.02
Séguéla	85.05	72.44
Tabou	151.15	131.80
Tiassalé	81.71	87.03
Toulepleu	88.56	95.33
Minimum	72.29	66.06
Maximum	152.67	140.87
Average	96.61	93.23

It emerges from his analysis that the normals of the extreme rains evaluated over the period of 1931-1970 vary between 72.29 and 152.67 mm with an average of 96.61 mm. For the period 1971-2010, the normal values oscillate between 66.06 and 140.87 mm with an average of 93.23 mm. The statistical characteristics (minimum, maximum and average) of the annual rainfall normals of the wet period (1931-1970) remain higher than those of the dry period (1971-2010).

Extreme rainfall quantiles analysis

The quantiles were evaluated over the 1931-1970 and 1971-2010 sub-periods through six (6) return periods (T = 2, 5, 10, 20, 50 and 100 years) (Tables 6 and 7). For the period of 1931-1970, the extreme rainfall quantiles of the 2-year return period are between 69.9 mm (Agnibilekro) and 146 mm (Tabou) with an average of 91.49 mm. Those of the 5-year return period oscillate between 83.8 (Agnibilekro) and 190 mm (Sassandra) with an average of 118.85 mm. As for the quantiles of the 10-year return period, they range from 92.9 mm (Agnibilekro) to 220 mm (Sassandra) with an average of 137.08 mm. As for the quantiles evaluated over the 20-year return period, they vary between 102 mm (Agnibilekro) and 248 mm (Sassandra)) with an average 137.08 mm. Regarding the 50-year return period quantiles, they oscillate between 113 (Agnibilekro) and 281 mm (Tabou) with an average of 281 mm. Finally, the 100-year return quantiles vary between 122 mm (Agnibilekro) and 310 mm (Grand Lahou). The quantiles calculated from the 1971-2010 period range from 57.40 (Ferkessédougou) to 131 mm (Aboisso) with an average of 84.85 mm for the return period of 2 years. For the return period of 5 years, the quantiles vary between 85.7 (Ferkessédougou) and 184 mm (Tabou) with an average of 119.32. Concerning the 10-year return period quantiles, they oscillate between 108 (Ferkessédougou) and 225 mm (Tabou) with an average of 143.42 mm. As for the 20-year return duration quantiles, they are between 123 (Dimbokro) and 263.0 mm (Tabou) with an average of 166.96. Regarding the rainfall quantiles with a return period of 50 years, they vary between 140 (Dimbokro) and 310 mm (Tabou) with an average of 198.42 mm.
The analysis of the quantiles shows that the quantiles for the period 1931-1970 are greater than the quantiles for the period 1971-2010 for the same return period.
In fact, the rainfall quantiles calculated from the 1931-1970 period and those of the 1971-2010 period increase with the periods of return.

Table 6: Extreme rainfall quantiles for the period 1931-1970

Stations	Quantiles (mm)					
	T = 2	T = 5	T = 10	T = 20	T = 50	T = 100
Abengourou	71.9	104	129	153	186	210
Abidjan	146	184	206	225	249	265
Aboisso	111	155	185	213	250	278
Agboville	76.7	95.3	105	112	120	124
Agnibilékro	69.9	83.8	92.9	102	113	122
Azaguié	85.3	115	136	157	186	210
Bouaflé	79.6	101	114	128	146	159
Bouaké	71.8	92.5	108	124	144	160
Bouna	73.4	93	104	115	127	135
Boundiali	82.8	108	132	164	223	285
Dabakala	78.7	98.7	112	125	141	153
Daloa	86.9	117	137	156	181	200
Dimbokro	71.9	93.6	108	122	140	153
Ferkéssedougou	83.6	107	122	137	156	171
Gagnoa	73.2	94.6	109	122	140	153
Grand Lahou	136	182	213	243	281	310
Guiglo	86	112	129	145	166	182
Lamé	128	161	183	204	231	252
Man	80.8	107	125	143	167	187
Mankono	90.5	117	134	148	165	177
Odienné	89.3	115	132	148	169	185
Sassandra	139	190	220	248	281	305
Séguéla	83.7	107	123	138	157	172
Tabou	146	189	218	246	281	308
Tiassalé	86.6	110	124	136	151	162
Toulepleu	85.1	108	124	139	158	172
Minimum	69.9	83.8	92.9	102	113	122
Maximum	146	190	220	248	281	310
Average	91.49	118.85	137.08	154.79	178.08	196.46

Table 7: Extreme rainfall quantiles for the period 1971-2010

Stations	Quantiles (mm)					
	T = 2	T = 5	T = 10	T = 20	T = 50	T = 100
Abengourou	73.30	113.00	145	181.0	235.0	284
Abidjan	123.00	165.00	191	213.0	241.0	260
Aboisso	131.00	182.00	217	249.0	292.0	323
Agboville	89.80	128.00	154	178.0	210.0	234
Agnibilékro	66.30	92.60	110	127.0	148.0	165
Azaguié	98.90	135.00	158	178.0	202.0	219
Bouaflé	86.60	103.00	125	148.0	182.0	209
Bouaké	60.90	94.60	122	153.0	201.0	243
Bouna	78.10	116.00	141	166.0	197.0	220
Boundiali	79.20	114.00	135	154.0	178.0	196
Dabakala	76.60	108.00	129	149.0	175.0	195
Daloa	74.00	102.00	122	142.0	171.0	194
Dimbokro	74.10	95.20	109	123.0	140.0	153
Ferkéssedougou	57.40	85.70	108	132.0	168.0	200
Gagnoa	78.30	103.00	120	137.0	160.0	177
Grand Lahou	118.00	168.00	200	231.0	272.0	302
Guiglo	104.00	149.00	179	208.0	245.0	272
Lamé	110.00	148.00	175	202.0	239.0	268
Man	76.50	107.00	126	143.0	163.0	178
Mankono	73.60	103.00	123	142.0	166.0	185
Odienné	68.80	95.30	111	126.0	144.0	156
Sassandra	92.60	134.00	166	199.0	248.0	289
Séguéla	59.00	99.20	130	160.0	200.0	231
Tabou	120.00	184.00	225	263.0	310.0	344
Tiassalé	77.60	109.00	133	158.0	193.0	222
Toulepleu	85.10	108.00	124	139.0	158.0	172
Minimum	57.40	85.7	108	123	140	153
Maximum	131	184	225	263.0	310	344
Average	84.85	119.32	143.42	166.96	198.42	222.79

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Comparison of standards

Comparison of normals

The analysis of the absolute relative deviations of the normals of annual and extreme rainfall made it possible to identify the binary matrices of the norms presented in Tables 8 and 9. It emerges from the analysis of these matrices that there is a representation of the two codes (0,1). Analysis of the annual rainfall normal matrix shows that fifty-two (52) values are greater than 1% or 100% of the stations (Table 8). Also, no value is less than 1%.

Table 8: Binary matrix of annual rainfall normal

Stations	Years	1931-1970	1971-2010	Stations	1931-1970	1971-2010
Abengourou	1931-1970	1	0	Ferkéssedougou	1	0
	1971-2010	0	1		0	1
Abidjan	1931-1970	1	0	Gagnoa	1	0
	1971-2010	0	1		0	1
Aboisso	1931-1970	1	0	Grand Lahou	1	0
	1971-2010	0	1		0	1
Agboville	1931-1970	1	0	Guiglo	1	0
	1971-2010	0	1		0	1
Agnibilékro	1931-1970	1	0	Lamé	1	0
	1971-2010	0	1		0	1
Azaguié	1931-1970	1	0	Man	1	0
	1971-2010	0	1		0	1
Bouaflé	1931-1970	1	0	Mankono	1	0
	1971-2010	0	1		0	1
Bouaké	1931-1970	1	0	Odienné	1	0
	1971-2010	0	1		0	1
Bouna	1931-1970	1	0	Sassandra	1	0
	1971-2010	0	1		0	1
Boundiali	1931-1970	1	0	Séguéla	1	0
	1971-2010	0	1		0	1
Dabakala	1931-1970	1	0	Tabou	1	0
	1971-2010	0	1		0	1
Daloa	1931-1970	1	0	Tiassalé	1	0
	1971-2010	0	1		0	1
Dimbokro	1931-1970	1	0	Toulepleu	1	0
	1971-2010	0	1		0	1

Regarding the normal annual maximum daily rains, fifty values (50) are greater than 1%, or 96.15% of the stations (Table 9). On the other hand, only one station (Agnibilekro) which presents values lower than 1%, that is to say 3.85%. The number of values greater than 1% being predominant then the difference between the different normals is significant. It therefore follows that the normals calculated over the wet (1931-1970) and dry (1971-2010) periods are not stationary.

Table 9: Binary matrix of extreme rainfall normals

Stations	Years	1931-1970	1971-2010	Stations	1931-1970	1971-2010
Abengourou	1931-1970	1	0	Ferkéssedougou	1	0
	1971-2010	0	1		0	1
Abidjan	1931-1970	1	0	Gagnoa	1	0
	1971-2010	0	1		0	1
Aboisso	1931-1970	1	0	Grand Lahou	1	0
	1971-2010	0	1		0	1
Agboville	1931-1970	1	0	Guiglo	1	0
	1971-2010	0	1		0	1
Agnibilékro	1931-1970	1	1	Lamé	1	0
	1971-2010	1	1		0	1
Azaguié	1931-1970	1	0	Man	1	1
	1971-2010	0	1		1	1
Bouaflé	1931-1970	1	0	Mankono	1	0
	1971-2010	0	1		0	1
Bouaké	1931-1970	1	0	Odienné	1	0
	1971-2010	0	1		0	1
Bouna	1931-1970	1	0	Sassandra	1	0
	1971-2010	0	1		0	1
Boundiali	1931-1970	1	0	Séguéla	1	0
	1971-2010	0	1		0	1
Dabakala	1931-1970	1	0	Tabou	1	0
	1971-2010	0	1		0	1
Daloa	1931-1970	1	0	Tiassalé	1	0
	1971-2010	0	1		0	1
Dimbokro	1931-1970	1	0	Toulepleu	1	0
	1971-2010	0	1		0	1

Comparison of quantiles

The analysis of the absolute relative deviations of the quantiles of the annual maximum daily rainfall made it possible to identify the binary matrices of the return periods (T = 2, 5, 10, 20, 50 and 100 years). It emerges from the analysis of the statistics of the binary matrices (Table 10) that there is a representation of the two codes (0,1). For the 2-year return period, 100% of values are greater than 1%. As for the return period of 5, 10 and 50 years, 92.31% is greater than 1%, on the other hand 7.69% remains below 1%. Regarding the 20-year return periods, 88.46% of values are above 1% and 11.54% remain below. For 100-year return periods, 96.15% of values are greater than 1% versus 3.85% less than 1%. The proportion of values greater than 1% being very high, this reflects a significant difference between the different quantiles for the same return period. It should be deduced that the calculated annual maximum daily rainfall quantiles are therefore not stationary.

Table 10: Proportions of the relative absolute deviations of the extreme rainfall quantiles

Return period (year)	2	5	10	20	50	100
Absolute deviation greater than 1%	100%	92.31%	92.31%	88.46%	92.31%	96.15%
Absolute deviation less than 1%	0%	7.69%	7.69%	11.54%	7.69%	3.85%

DISCUSSION

The relative deviations evaluated at the level of the annual rainfall norms of the 26 stations studied show that all the values are greater than 1%. Regarding the norms of annual maximum daily rainfall, 96.15% are greater than 1%. The analysis of the relative absolute deviations between the quantiles of annual maximum daily rainfall show that the smallest deviations are obtained with return periods less than or equal to 10 years and are between 0.92% and 46.67%. On the other hand, for return periods exceeding 10 years, the differences vary between 0.61% and 88.71%. These main results show that the standards studied (annual rainfall norms, annual maximum daily rainfall norms and annual maximum daily rainfall quantiles) are non-stationary due to climate instability.
According to the work of [8], the absolute relative differences between the different normals of the annual maximum daily rainfall (1931-1960, 1941-1970, 1951-1980 and 1961-1990) at the Port-Bouët station (Abidjan) indicate several groupings. First, a first group is highlighted, characterized by absolute relative deviations of less than 5% between the normals for the periods 1931-1961, 1941-1970, 1951-1980 and 1961-1990. Then, a second regrouping is observed and characterized by absolute relative differences of less than 5% between the normals of the periods 1971-2000 and 1981-2020. Finally, the last group is marked by a single normal (1991-2020), with absolute relative deviations greater than 5% with the other normals. Significant differences are highlighted between the normals for the 1931-1990 period on the one hand and the normals for the 1971-2020 and 1991-2020 periods on the other hand. The absolute relative deviations between the different normals of the annual maximum daily rainfall and the average of the entire series indicate that only the normals of the periods 1961-1990 and 1971-2000 have relative deviation values of less than 5%.
[6] has shown in Cameroon the relative differences in annual rainfall accumulations between the reference period (1951-1980) and the others (1941-1970, 1951-1980, 1961-1990, 1971-2000), including the average value calculated based on the observation period 1941-2000. The differences between the 1941-1970 and 1951-1980 normals are relatively modest. They are between –5 and + 5% over almost the entire territory. The margin of error involved in using one instead of the other is relatively small. We can conclude that they are equivalent. Between the 1961-1990 and 1951-1980 normals, the differences become more and more important, especially in the northern part of the country where they can reach 20% (100 to 200 mm difference depending on the region). The margins of error are becoming more and more important and the interchangeability of normals presents a considerable risk. The differences are even greater between the 1971-2000 and 1951-1980 normals. The range representing the differences of 5 to 10% between the two normals covers more than half of the country while the range 10 to 15% concerns the entire far north, the region of Mount Cameroon and part of the western mountainous region of country. The average values calculated over all the data for the observation period (1941-2000) are generally lower than those for the usual reference period. The differences between the two normals, however, remain modest overall. They are between 0 and 5% and can be considered negligible.
A comparison of the annual rainfall norms over 30 years with the average values for 1941-2000 was also carried out by [6]. According to the author, lhe period 1941-2000 has the statistical advantage of being longer and of integrating both all the dry and wet decades of the observation period. The values of the normal 1941-1970 and 1951-1980 are overall higher than the average for the period 1941-2000, unlike those for the periods 1961-1990 and 1971-2000. However, apart from the extreme north of the country and a few regions such as Mount Cameroon and the extreme south-east, the differences remain around 5%. It can be concluded that the average calculated on all the data remains globally closer to the other normals calculated over periods of 30 years.
The work of [3] on the pluviometric station of Port-Bouët (Abidjan) revealed two trends in terms of the quantiles of annual maximum daily rainfall. The first trend concerns the quantiles of the return periods equal to 2 and 5 years. In fact, as many relative absolute deviation values less than or equal to 5% are recorded as there are values greater than 5%. In this trend, the differences between the two reference periods [historical reference period (1961-1190) and updated reference period (1981-2010)] are the largest. The second trend concerns the quantiles of the return periods equal to 10, 20, 50 and 100 years. At this level, more absolute relative deviation values less than or equal to 5% are recorded than values greater than 5%. In this trend, the differences between the two reference periods [historical reference period (1961-1990) and updated reference period (1981-2010)] are the smallest. The differences between, on the one hand, the quantiles of the historical reference period (1961-1990) and the other quantiles are the highest regardless of the return period. Conversely, the differences between, on the one hand, the quantiles of the updated reference period (1981-2010) and the other quantiles are the smallest regardless of the return period. In general, the differences decrease with the duration of the return. The

differences between, on the one hand, the quantiles of the historical reference period (1961-1990) and the other quantiles are the highest regardless of the return period. Conversely, the differences between, on the one hand, the quantiles of the updated reference period (1981-2010) and the other quantiles are the smallest regardless of the return period. In general, the differences decrease with the duration of the return. The differences between, on the one hand, the quantiles of the historical reference period (1961-1990) and the other quantiles are the highest regardless of the return period. Conversely, the differences between, on the one hand, the quantiles of the updated reference period (1981-2010) and the other quantiles are the smallest regardless of the return period. In general, the differences decrease with the duration of the return. These results show that the quantiles differ more at low return periods (2, 5 years). However, for large return periods, and therefore rains of rare or very rare frequencies, the difference between the quantiles is not statistically significant. It can be concluded that in general, the quantiles are very different at low return periods (2, 5 and 10 years). However, they remain statistically equivalent to the major return periods (20, 50 and 100 years). This fact is more remarkable for the quantiles of the standard reference periods (1961-1990; 1981-2010).
To always appreciate the impact of climate change on standards, some authors such as [15] made predeterminations of the mean annual maximum daily flows from Niger to Koulikoro by splitting the total sample of observations into two parts, before and after 1970. The adjustment over the period 1971 to 1992 shows an underestimation. 24% compared to the results obtained considering the entire observation period.
For the study of the non-stationarity of standards, a comparative analysis of the modules of three rivers in West Africa [10] shows that the differences can be very significant in certain cases. Thus, a ratio of 2.5 was observed between the norm calculated over the period 1971-2000 and that calculated over the period 1951-1980, on the Bani at Douna. For all three rivers studied, the millennial flow calculated over the 1971-2000 period (dry period) is lower than the ten-year flow during the 1951-1980 period (wet period).
The results obtained during this study are in agreement with those of previous work ([3]; [6]; [8]; [10]; [15]). Indeed, the current climate changes have affected hydrological standards in West Africa and pose the problem of the choice of the reference period in the definition of hydrological standards.

CONCLUSION

This study was devoted to the analysis of the stationarity of hydrological standards in a context of climate change in West Africa, more precisely in Ivory Coast. The analysis of the normals of the annual rains and of the extreme rains shows that the statistical characteristics of the normals (minimum, maximum and average) of the wet period (1931-1970) are superior to those of the dry period (1971-2010). The quantiles calculated over the different periods (1931-1970; 1971-2010) from several return periods (2, 5, 10, 20, 50 and 100) vary for a given return period, from the wet period to the dry period. The quantiles calculated for the wet period (1931-1970) remain higher than those determined for the dry period (1971-2010). The analysis of the binary matrices of the annual rainfall normals shows that 100% of the values are greater than 1%. Regarding the normals of extreme rains, 96.15% are higher than 1%, on the other hand 3.85% remain lower. In general, the percentage of values greater than 1% being then preponderant, the differences on the one hand between the normals of the annual rains and on the other hand between the norms of the extreme rains are significant. It therefore follows that the normals of the annual rains and the norms of the extreme rains (annual maximum daily rains) calculated on the one hand over the wet period (1931-1970) and on the other hand over the dry period (1971-2010) are not stationary. 15% are higher than 1%, on the other hand 3.85% remain lower. In general, the percentage of values greater than 1% being then preponderant, the differences on the one hand between the normals of the annual rains and on the other hand between the norms of the extreme rains are significant. It therefore follows that the normals of the annual rains and the norms of the extreme rains (annual maximum daily rains) calculated on the one hand over the wet period (1931-1970) and on the other hand over the dry period (1971-2010) are not stationary. 15% are higher than 1%, on the other hand 3.85% remain lower. In general, the percentage of values greater than 1% being then preponderant, the differences on the one hand between the normals of the annual rains and on the other hand between the norms of the extreme rains are significant. It therefore follows that the normals of the annual rains and the norms of the extreme rains (annual maximum daily rains) calculated on the one hand over the wet period (1931-1970) and on the other hand over the dry period (1971-2010) are not stationary. The analysis of the absolute relative deviations of the quantiles of the annual maximum daily rainfall revealed a rate of values greater than 1% varying between 88 and 100% regardless of the return period (T = 2, 5, 10, 20, 50 and 100 years). The proportion of values greater than 1% being very large, then the difference between the different

quantiles is significant. It should be deduced that the calculated annual maximum daily rainfall quantiles are therefore not stationary.
Since the norms of annual rainfall, the norms of extreme rainfall and the quantiles of extreme rainfall are non-stationary, then the standards studied are non-stationary regarding the instability of the climate. The estimated standards are a decision support tool for designers and engineers with regard to the sizing of hydraulic structures, the study of climatic regimes, the management of water resources, etc. in a context of climate change, then the problem arises of the choice of the reference period to serve as a basis for the definition of hydrological standards in West Africa.

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