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Actualization of Climatic Parameters of the Empirical Methods of ORSTOM and CIEH: Case of Ivory Coast

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Abstract: Climate change is a reality that affects several climate variables including precipitation. This change and the variability of the climate are considered to be the greatest challenges facing humanity in the decades to come, on all geographic scales and in all economic sectors. In this context of severe climate change, it will be judicious to review the sizing parameters of hydraulic structures. The determination of hydrological standards is necessary within the framework of development projects for the design of hydraulic structures and the storm water management. The objective of this study is to update the parameters of the ORSTOM and CIEH methods. These are annual rainfall normals, extreme rainfall norms, extreme rainfall quantiles as well as the extreme rainfall gradex. The study carried out was based on annual maximum daily rainfall data and annual rainfall data collected over the period 1931-2020 from twenty-six (26) rainfall stations. The methodological approach is based on the one hand on the evaluation of the normals (normals of annual rainfall, norms of extreme rainfall) and on the other hand on the determination of the quantiles of the daily maximum annuals. These quantiles were used to assess the extreme rainfall gradex. The annual rainfall norms evaluated over the period 1931-2020 vary between 1,180 and 1,457.4 mm. As for the normals of the maximum daily rains, they oscillate between 73.61 mm (Agnibilékro) and 136.59 mm (Tabou) with an average of 94.57 mm. The 10-year return period quantiles evaluated over the period 1931-2020 vary between 103 mm (Dimbokro) and 222 mm (Tiassalé) with an average of 143.6 mm. As for the centennial quantiles, they oscillate between 132 mm (Dimbokro) and 326 mm (Tiassalé) with an average of 211.5 mm. An analysis of the extreme rainfall gradex revealed values fluctuating between 0.28 (Dimbokro) and 0.71 (Guiglo) with an average of 0.47 on Ivorian territory. The gradex coefficients determined are all greater than the regional value of 0.38 defined by ORSTOM except for the Dimbokro station (0.28). Indeed, the calculated gradex coefficient biases are all positive (ranging from +2.63 to + 86.84%) except that of Dimbokro (-26.32%). The use of the regional value of 0.38 reflects an under designing of the values of the gradex coefficient for the whole country except the Dimbokro station.

Keywords: Empirical Methods of ORSTOM and CIEH, Hydrological Standards, Ivory Coast

1. Introduction

In a context of modified climatic parameters, it appears necessary to review the designing parameters of hydraulic structures. Knowledge of hydrological standards, such as extreme precipitation quantiles as well as extreme and annual rainfall normals, are necessary in the context of development projects for the design of hydraulic structures (flood protection structures, networks sewerage, etc.) and in many engineering applications.

In West Africa, apart from the series of works carried out by the Inter-African Committee for Hydraulic Studies [1] and which serves as a reference for engineers, very few studies have been devoted to the analysis of extreme rains [1-3].

The estimation of the recurrence of extreme rains provides essential elements for the construction of hydraulic infrastructures [4]. An overestimation leads to over-sizing of structures thus leading to additional construction costs, while an underestimation can lead to risks of flooding, ruptures of structures and loss of human life. The increase in the frequency of extreme events, such as floods and very intense rains, had been mentioned by several authors [5]. These extreme weather and climate events will condition vulnerability to future extreme events by modifying already fragile ecosystems [6]. The occurrence of these exceptional episodes prompts a review of the hydrological standards (normal annual rainfall, normal annual maximum daily rainfall, quantiles of maximum annual daily rainfall) in Ivory Coast. Indeed, this country is facing climate change, the impacts of which consist of obvious coastal erosion, frequent flooding, landslides, the emergence of certain diseases such as typhoid fever, land degradation, and loss. of biodiversity [7]. In recent years, the economic capital Abidjan and some cities (Grand Lahou, Dimbokro, M'Bahiakro, Bouaflé, etc.) have suffered from floods and landslides during the great rainy season causing extensive material and human damage. The validity of the ten-year and one-hundred-year flood predetermination methods prescribed by ORSTOM hydrologists is increasingly questioned [2]. This issue raises the following main question: "On what basis could / should we develop new hydrological standards for the management of new construction projects for hydraulic structures?"

Also, would the various climatic parameters incorporating the sizing methods and formulas for these structures be adapted to the climatic instability observed in Ivory Coast? In West and Central Africa in general, and in Ivory Coast in particular, hydraulic structures are often designed using the methods of the Office for Scientific and Technical Research Overseas (ORSTOM) [8] and the Inter-African Committee for Hydraulic Studies [9]. In the application of these empirical methods, decadal and centennial rainfall maps have been established, based on past data, themselves affected by the phenomenon of climate change. These established maps often relate to times that are much out of date nowadays.

In the application of these empirical methods, decadal and centennial rainfall maps have been established, based on past data, themselves affected by the phenomenon of climate change. These established maps often relate to times that are much out of date nowadays. To determine the 100-year flood (project flood) from the 10-year flood, a major coefficient, greater than 1, is used, which depends, among other parameters, on the 10-year (P_{10}) and 100-year (P_{100}) rainfall. This coefficient is called gradex (gradient of extreme values). According to the authors of these methods, the gradient takes the value 0.45 in the Sahelian zone and 0.38 in the tropical zone. Indeed, the gradex is a seasonal and local climatological invariant depending on the geographical location [10]. However, in a context of non-stationarity of rainfall normals, the validity of such a principle is questionable. In a context potentially amplifying the frequency and intensity of extreme rainfall and hydrological events as experienced by Ivory Coast, the validity of the predetermination methods for decennial and centennial floods prescribed by ORSTOM hydrologists is increasingly questioned [2, 11]. This issue raises the following main question: "On what basis could / should we develop new quantiles for the management of new construction projects for hydraulic structures?"

Thus, the objective of this work is to update the climatic parameters of the empirical methods of ORSTOM and CIEH in Côte d'Ivoire. This is a contribution to the debate on the revision of hydrological standards.

2. Materials and Methods

2.1. Presentation of the Study Area

Ivory Coast is located 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 in the North. Figure 1 shows the study area which is Ivory Coast.

In Ivory Coast, there are four main climatic zones (Figure 2): the tropical transition regime or Sudanese climate in the north, the equatorial transition regime attenuated or Baoulean climate in the center, the equatorial transition regime or climate Attiéen in the South and the mountain regime or mountain climate in the West. The standard precipitation index (SPI) applied to the annual rains highlighted the different periods of surplus and deficit over the period 1931-2020 (Figure 3). In general, the period before 1970 is characterized by positive rainfall indices and that after 1970 is marked by negative rainfall indices.

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 [12]. The Guinean domain has a predominantly dense humid forest vegetation. There are 4 sectors characterized by particular plant groups responding to different ecological conditions [12]. 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 1.__ Presentation of the study area (Ivory Coast).

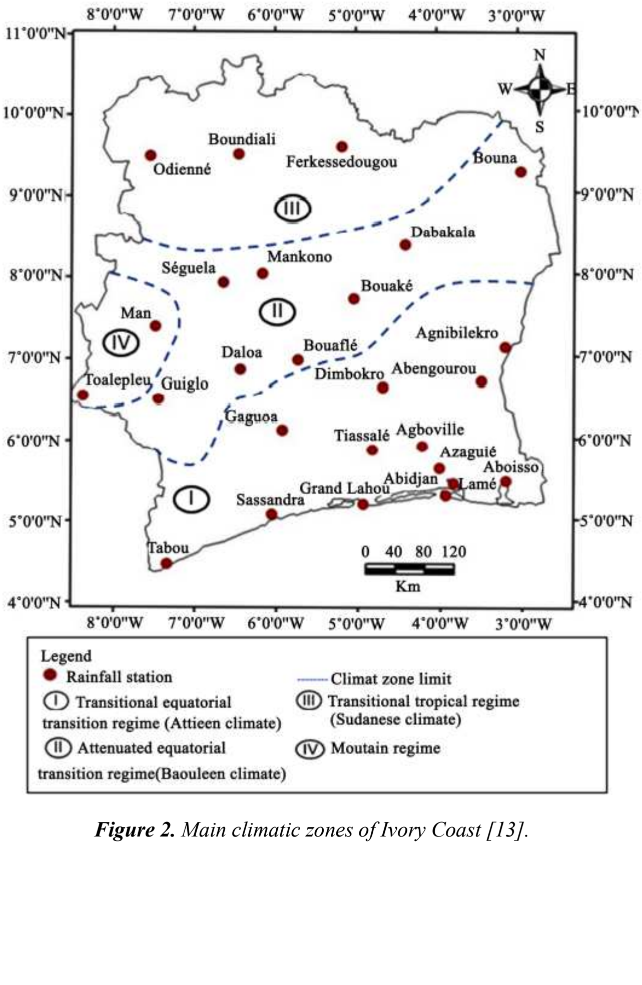

__Figure 2.__ Main climatic zones of Ivory Coast [13].

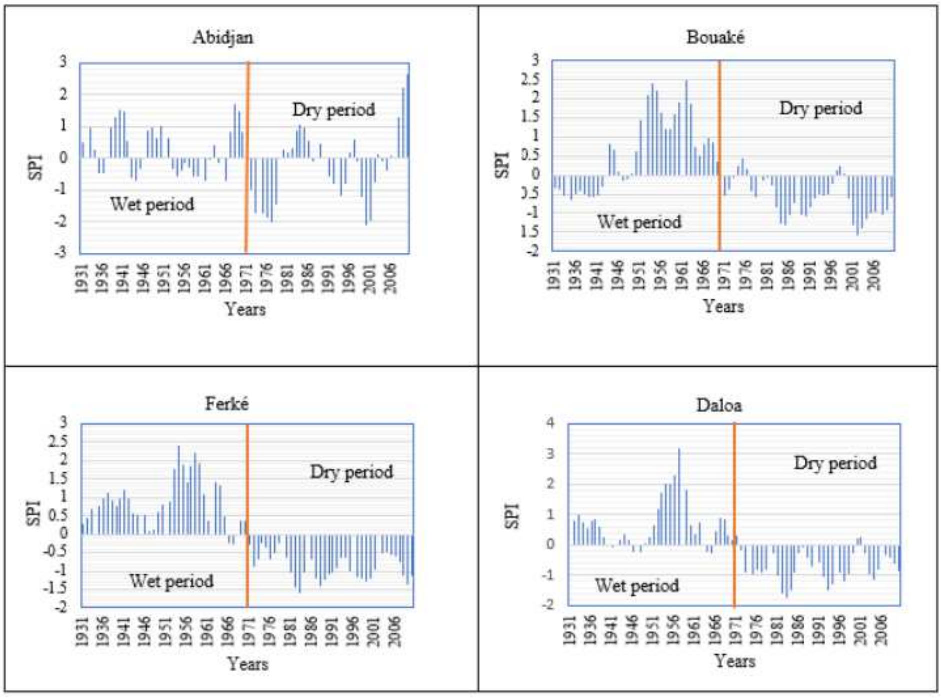

Figure 3. *Standard annual rainfall indices for some stations in Ivory Coast (1931-2020).*

2.2. Data

The data used to carry out this study come from the national meteorological measurement network of Ivory Coast. The annual maximum daily rainfall data used covers the period 1931-2020 and comes from twenty-six (26) rainfall stations distributed throughout the country (Figure 4). They were made available to us by SODEXAM (Aeronautical, Airport and Meteorological Development and Exploitation Company). The choice of stations was guided by the availability and quality of chronological data (fewer gaps with a threshold of 5%).

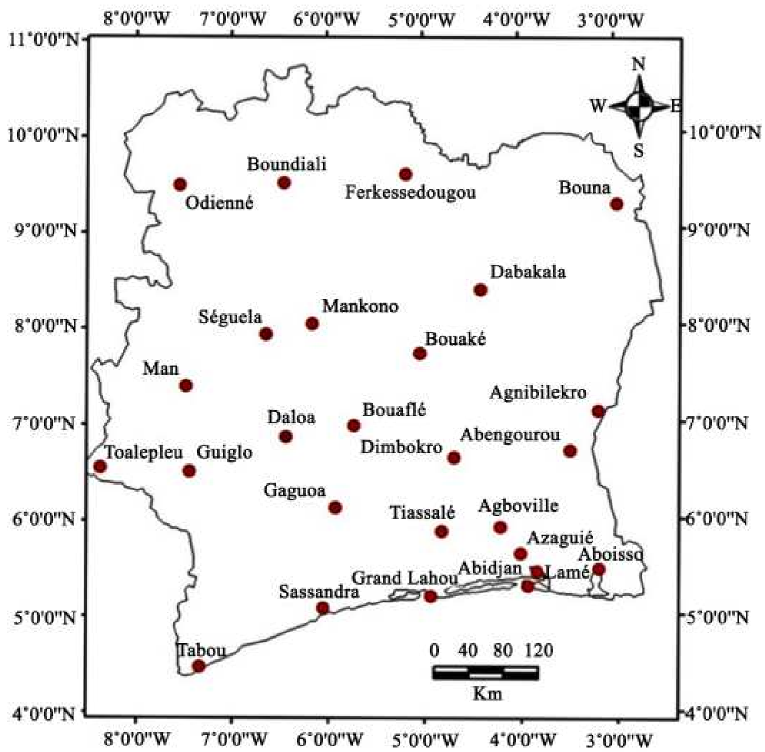

Figure 4. *Location of selected rainfall stations.*

The various data have undergone preprocessing. Indeed, the method of double cumulations and single residuals was applied to the data of extreme rainfall 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.

2.3. Determination of Climatic Parameters of the ORSTOM and CIEH Method

The main results of the work of Nassa et al. (2021) on the sensitivity of statistical laws have shown that the 30-year series are better adjusted by the Gumbel (26.92 - 53.85%) and inverse Gamma (26.92 - 46,15%) laws. The supremacy of Gumbel's law deteriorates from the wet period (1931-1960) with an occurrence rate of 53.85% in the dry period (1991-2020) (26.92%) in favor of the Gamma law Inverse with respective probabilities of 46.15% (1961-1990) and 42.31% (1991-2020). Regarding the 60-year series, they are better adjusted by the inverse Gamma (30.77%), Gamma (15.38 - 46.15%) and Gumbel (15.38 - 42.31%) laws. The Gumbel law is predominant over the first relatively wet period (1931-1960) with an occurrence rate of 42.31%. As for the second relatively less humid period (1991-2020), it is dominated by the Gamma (46.15%) and Inverse Gamma (30.77%) laws. The complete chronicle of 1931-2020 presents a notable supremacy of 50% of the Gumbel law over the Gamma (34.62%) and Gamma Inverse (15.38%) laws. It is noted that the Gumbel law is the most dominant law overall and more particularly in wet periods. The data for periods with normal and dry trends were better fitted by the Gamma and Inverse Gamma laws. The laws used to adjust the annual maximum daily rainfall data are therefore sensitive to the size of the samples and to the climatic context of the series. Indeed, the laws are more stable when the size of the data series becomes large (at least 60 years) and when the series considers a wet component (before 1970) and a dry component (after 1970) [14].

The results of the work of [14] have shown that the reference periods for calculating the quantiles chosen by the designers of hydraulic structures experience instability due to the non-stationarity of the climate during the study period considered. Therefore, the entire period 1931-2020 was used in this work to determine the hydrological norms such as the normals of annual rainfall and maximum daily rainfall as well as the extreme rainfall quantiles (decennial and centennial) and the extreme rainfall gradex.

The annual rainfall normals and those of the annual maximum daily rainfall were calculated using the average [15, 16] and over the sub-periods 1931-1970 and 1971-2010. 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 a single one. This is the main feature that serves as the starting point for most standards.

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]:

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

With:

x_0: the arithmetic mean;

S: the standard deviation of the sample considered;

u: reduced variable of the considered law.

x_0 and S being known, we compute x(F), which is the desired quantile.

Thus, the quantiles of annual maximum daily rainfall were calculated over the period 1931-2020 for several return durations (T: 2, 5, 10, 20, 50 and 100 years) [3].

2.3.1. Determination of Climatic Parameters of the ORSTOM Method

The ORSTOM method makes it possible to assess the flow of the ten-year flood in the basins of the Sahelian and tropical zone. The method applies to basins with an area between a few tens of hectares up to 1,500 km². The ten-year flood flow is evaluated using the following equations [17]:

$$Q_{10} = K \times Q_m \tag{2}$$

$$Q_m = \frac{V_r}{T_h} \tag{3}$$

$$V_r = K_r \times C_q(T, S, P_{an}) \times S \times P_{10} \tag{4}$$

Several formulas are used to calculate the reduction coefficient (C_a) such as the Vuillaume formula:

$$C_a = 1 - 0.001 \times (9logT - 0.042P_{an} + 152) \times logS \tag{5}$$

For a return period of 10 years we have:

$$Q_{10} = \frac{K \times K_r \times S \times P_{10} \times (1 - 0.001 \times (161 - 0.042P_{an}) \times logS}{T_h} \tag{6}$$

With T: return period (year);

P_{an}: interannual average rainfall (mm);

Q_{10}: the ten-year maximum flow in m^3/s;

K: the crest coefficient;

P_{10}: daily punctual decadal precipitation;

K_r: the decennial runoff coefficient;

S: the area of the watershed in km^2;

T_b: the base time in seconds.

The parameters studied in the ORSTOM formula are the decennial rainfall (P_{10}) and the interannual mean rainfall (P_{an}).

2.3.2. Determination of Climatic Parameters of the CIEH Method

The CIEH method was developed on the basis of measurements and observations carried out on 162 basins to estimate the ten-year flood. It applies to the watersheds of Sahelian and dry tropical Africa with an area of less than 2,500 km² and an annual rainfall of less than 2,000 mm. The method is presented in the form of linear regression between the different parameters. The ten-year flood is evaluated using equation 7 [17]:

$$Q_{10} = aS^s \times {P_{an}}^p \times {I_R}^i \times {K_{r10}}^k \tag{7}$$

where: a, s, p, i, k are coefficients to be determined and,

Q_{10}: the ten-year flood flow (m^3/s);

S: basin area (km^2);

Ig: global slope index (m/km);

P_{an}: average annual rainfall (mm);

K_{r10}: decennial runoff coefficient (%).

The parameter being studied in the CIEH method is the mean annual rainfall (P_{an}).

2.3.3. Determination of the Gradex of the Empirical Methods of ORSTOM and CIEH

An analysis of the gradex of the ORSTOM and CIEH methods, generally used by practitioners for the determination of the design flood was carried out [3]. Indeed, the transition from the ten-year flood to the 100-year flood (project flood) is made possible thanks to a multiplying coefficient C (greater than 1). The value of the coefficient called gradex (λ) is 0.45 for the Sahelian zones and 0.38 for the tropical zones. The expression of this majorizing coefficient is (Equation 8):

$$C = 1 + \frac{P_{100}-P_{10}}{P_{10}} \times \frac{\left(\frac{T_b}{24}\right)^{0.12}}{K_{r10}} \quad (8)$$

With:

P_{10}: daily precipitation corresponding to a return period of 10 years;

P_{100}: daily precipitation corresponding to a return period of 100 years;

T_b: base time in hours;

K_{r10}: decadal flood runoff coefficient (expressed as a fraction and not as a percentage);

T_b and K_{r10} remain constant for a given basin.

We call the gradex coefficient (λ) the following expression (equation 9):

$$\lambda = \frac{P_{100}-P_{10}}{P_{10}} \quad (9)$$

3. Results and Discussion

3.1. Analysis of Annual and Extreme Rainfall Normals

The annual and extreme rainfall of the different stations and their statistical characteristics (minimum, maximum and average) are presented in Table 1. The annual rainfall normals evaluated over the period 1931-2020 vary between 1,180.41 mm (Agnibilékro) and 1,878.01 mm (Abidjan) with an average of 1,457.4 mm. As for the normals of the annual maximum daily rains evaluated over the period 1931-2020, they oscillate between 73.61 mm (Agnibilékro) and 136.59 mm (Tabou) with an average of 94.57 mm.

Table 1. *Statistical characteristics of annual and extreme rainfall norms (1931-2020).*

Stations	Annual rainfall norms 1931-2020	Extreme rainfall norms 1931-2020
Abengourou	1,352.77	83.45
Abidjan	1,878.01	136.44
Aboisso	1,801.71	132.77
Agboville	1,376.09	87.11
Agnibilékro	1,180.41	73.61
Azaguié	1,663.75	97.42
Bouaflé	1,301.12	80.22
Bouaké	1,604.41	74.40
Bouna	1,246.64	79.13
Dabakala	1,226.57	82.12
Boundiali	1,374.08	90.41
Daloa	1,330.26	86.12
Dimbokro	1,222.57	75.93
Ferkéssedougou	1,273.21	75.59
Gagnoa	1,440.21	81.57
Grand-Lahou	1,584.39	136.59
Guiglo	1,577.09	99.38
Lamé	1,600.04	125.40
Man	1,600.35	83.04
Mankono	1,281.41	83.01
Sassandra	1,544.22	119.86
Séguéla	1,285.67	78.68
Odienné	1,464.11	81.25
Tiassalé	1,276.77	87.32
Tabou	1,785.82	136.48
Toulepleu	1,620.67	91.45
Maximum	1,878.01	136.59
Minimum	1,180.41	73.61
Mean	1,457.4	94.57

The annual rainfall normals for the entire 1931-2020 period have been mapped and are presented in Figure 5. The 1,500 mm isohyet is considered on these maps as the reference isohyet in order to better understand the evolution of values. Indeed, the reference isohyet is located in the Center and extends from the West to the South-East of the country. In general, a decrease in normals is perceptible from the Center to the North and the North-East.

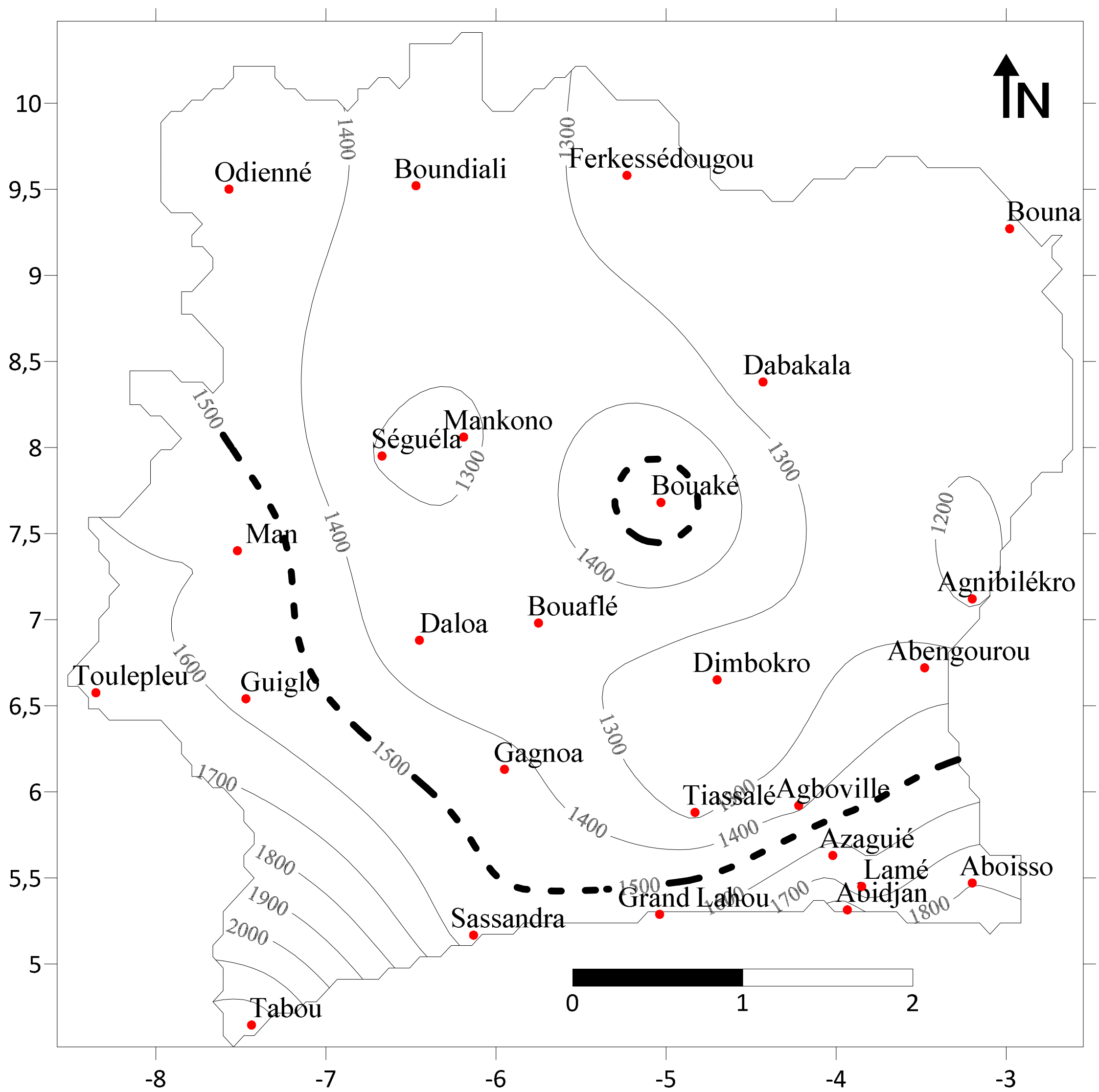

Figure 5. *Mapping of annual rainfall normal.*

3.2. Analysis of Decennial and Centennial Quantiles

The decennial and centennial quantiles of the various stations and their statistical characteristics are shown in Table 2. In fact, the 10-year return period quantiles evaluated over the period 1931-2020 vary between 103 mm (Dimbokro) and 222 mm (Tiassalé) with an average of 143.6mm. As for the centennial quantiles, they oscillate between 132 mm (Dimbokro) and 326 mm (Tiassalé) with an average of 211.5 mm.

Table 2. *Statistical characteristics of ten-year and one-hundred-year rains.*

Stations	Ten-yearly rains 1931-2020	Centennial rains 1931-2020
Abengourou	130	219
Abidjan	205	300
Aboisso	205	306
Agboville	132	195
Agnibilékro	107	154
Azaguié	144	210
Bouaflé	118	171
Bouaké	113	167
Bouna	121	181
Dabakala	142	215
Boundiali	124	183
Daloa	128	186
Dimbokro	103	132

Stations	Ten-yearly rains 1931-2020	Centennial rains 1931-2020
Ferkéssedougou	116	164
Gagnoa	117	174
Grand-Lahou	206	286
Guiglo	156	266
Lamé	182	263
Man	126	174
Mankono	127	179
Sassandra	123	171
Séguéla	192	280
Odienné	125	180
Tiassalé	222	326
Tabou	129	188
Toulepleu	140	230
Maximum	222	326
Minimum	103	132
Mean	143.6	211.5

The decennial and centennial quantiles have been mapped and are represented respectively by Figures 6 and 7. For decadal and centennial rainfall, respectively the 150 mm and 200 mm isohyet are considered as the reference isohyet in order to better understand the evolution. values. Indeed, the ten-year rains are high in the South-East of the country and part of the West (130 mm - 150 mm). They are generally weak in the North, East and Center and remain below 130 mm). As for the hundred-year rains, they are high in the south-east and west of the country (200 mm - 300 mm). They are weak in the Center and the North of the country (less than 200 mm).

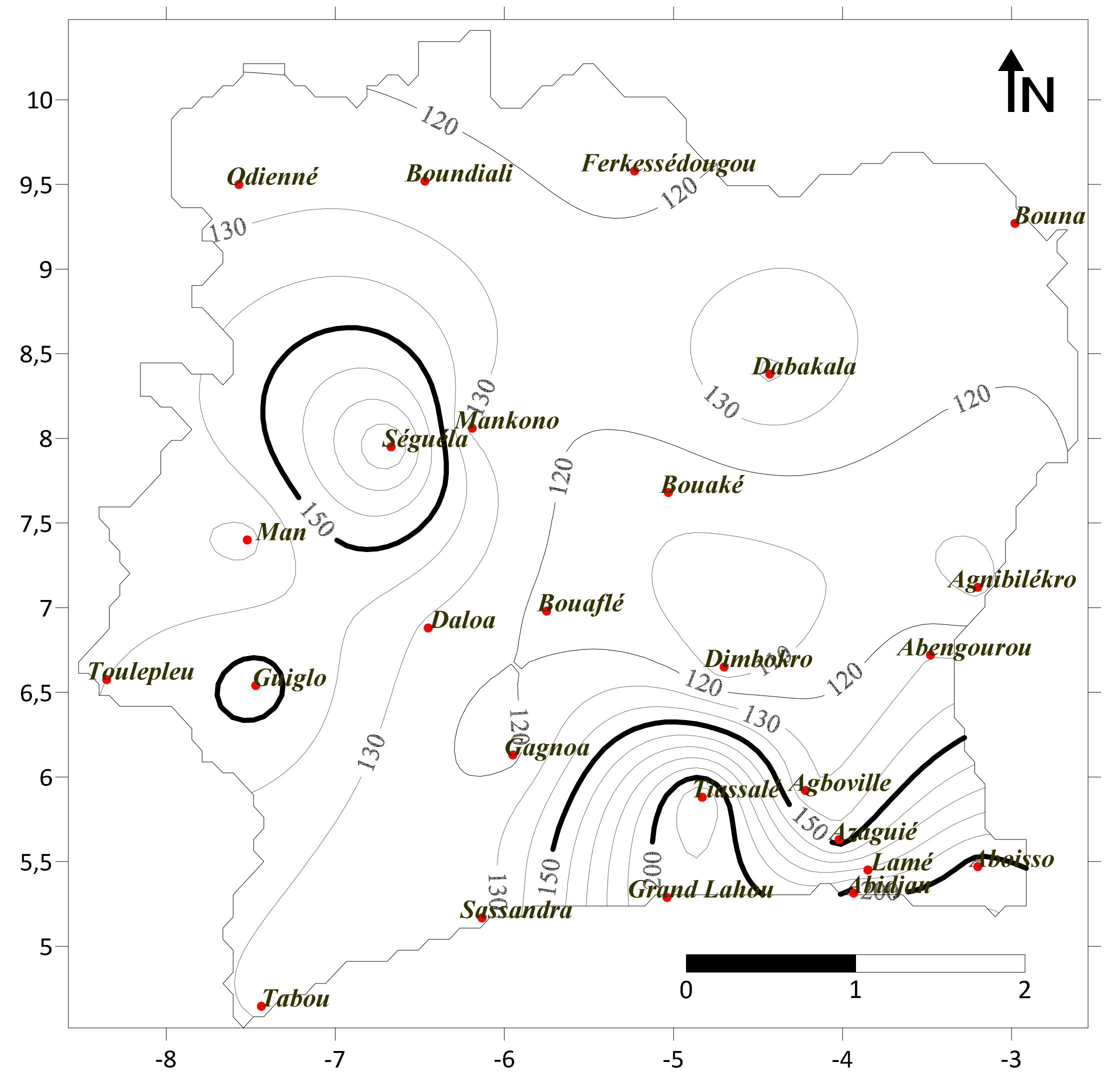

Figure 6. *Mapping of ten-year rainfall (1931-2020).*

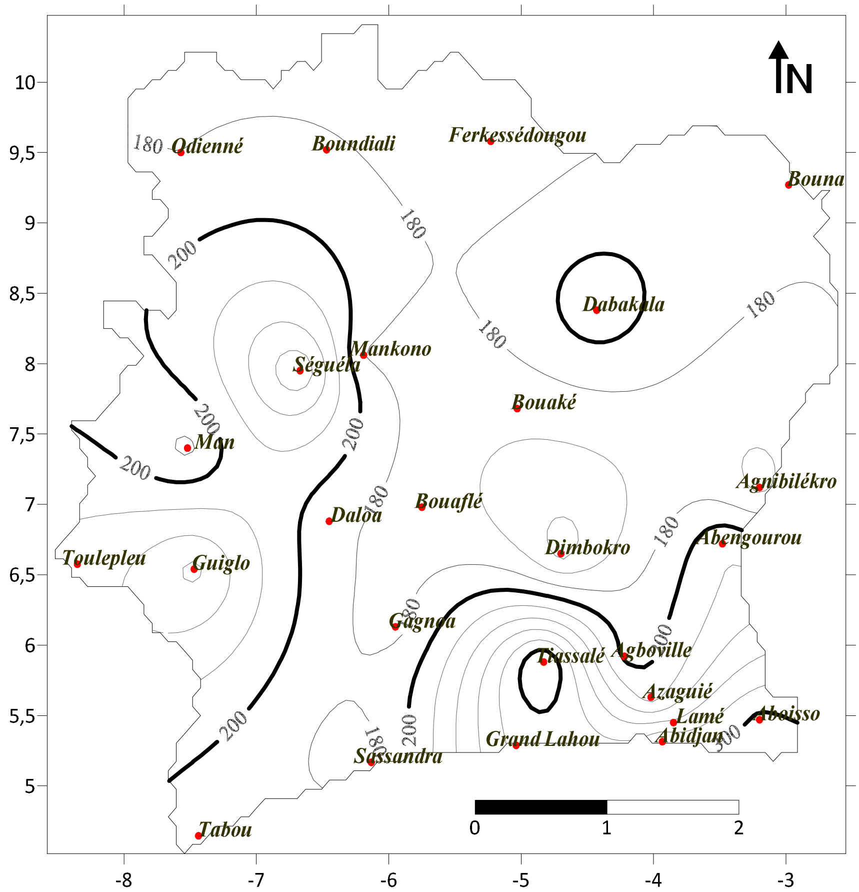

Figure 7. *Mapping of 100-year rains (1931-2020).*

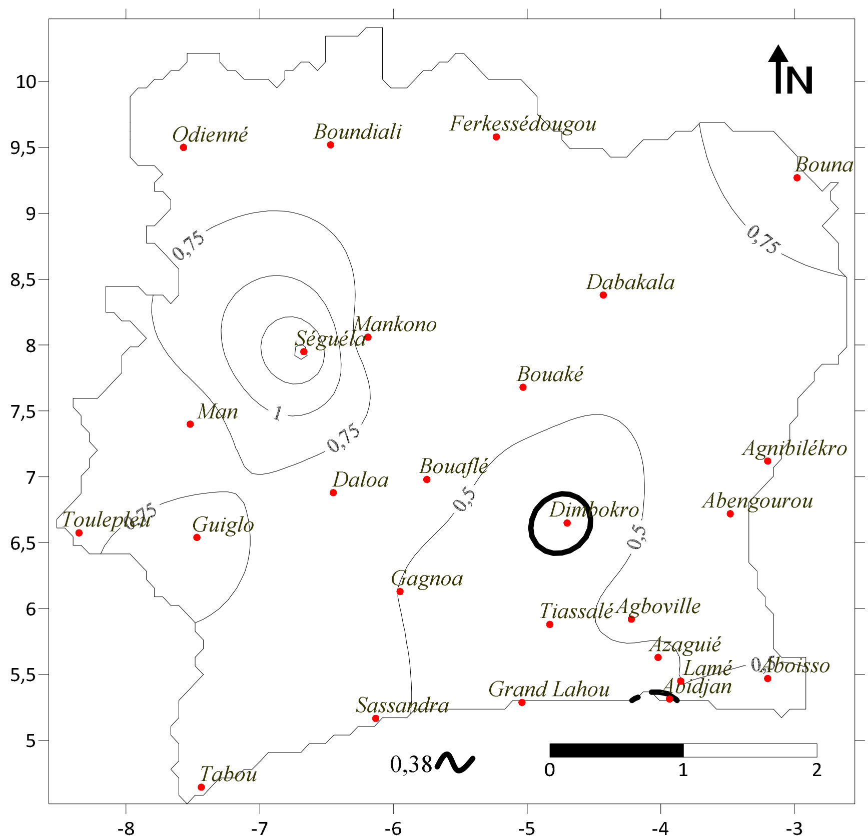

Figure 8. *Mapping of the gradex coefficient (1931-2020).*

3.3. Gradex Coefficient (λ)

The different values of the gradex coefficient (λ) of the ORSTOM and CIEH methods evaluated on the complete 1931-2020 chronicle and the relative deviations of the local gradex coefficients from the regional value of the gradex coefficient are recorded in the table 3. These values vary between 0.28 (Dimbokro) and 0.71 (Guiglo). The gradex coefficients determined are all greater than the regional value of 0.38 defined by ORSTOM except for the Dimbokro station (0.28). The values of the standard deviation (0.09) and of the coefficient of variation (18.69%) show a homogeneity of the values of the coefficient of gradex. The average gradex value in Ivory Coast is 0.47. The calculated gradex coefficient biases are all positive (+) except that of Dimbokro (-26.32%).

Table 3. *Gradex coefficients and relative bias to regional value.*

Stations	Gradex 1931-2020	Bias of gradex compared at 0.38 (%)
Abengourou	0.68	+78.95
Abidjan	0.46	+21.05
Aboisso	0.49	+28.95
Agboville	0.48	+26.32
Agnibilékro	0.44	+15.79
Azaguié	0.46	+21.05
Bouaflé	0.45	+18.42
Bouaké	0.48	+26.32
Bouna	0.50	+31.58
Dabakala	0.51	+34.21
Boundiali	0.48	+26.32
Daloa	0.45	+18.42
Dimbokro	0.28	-26.32
Ferkéssedougou	0.41	+7.89
Gagnoa	0.49	+28.95
Grand-Lahou	0.39	+2.63
Guiglo	0.71	+86.84
Lamé	0.45	+18.42
Man	0.38	0
Mankono	0.41	+7.89
Sassandra	0.39	+2.63
Séguéla	0.46	+21.05
Odienné	0.44	+15.79
Tiassalé	0.47	+23.68
Tabou	0.46	+21.05
Toulepleu	0.64	+68.42
Maximum	0.71	86.84
Minimum	0.28	-26.32
Mean	0.47	24.09
Standard deviation	0.09	
CV* (%)	18.69	

*CV: Coefficient of variation.

The use of the regional value of 0.38 reflects an underdimensioning of the values of the gradex coefficient for the whole country except the Dimbokro station. The estimate of the gradex of this study coincides with the regional value of 0.38 for the Man station (0% bias) and remains close for the Ferkéssedougou and Mankono stations (+7.89%). The Grand Lahou and Odienné stations show a low bias of 2.63%. These cities present a non-significant difference (bias less than 10%) compared to the regional value of 0.38.

The values of the gradex coefficient are represented in figure 8, spatially over the whole of Ivory Coast. These values are higher in the West towards Guiglo and Séguéla and in the North-East towards Bouna. The value less than 0.38 is observed at Dimbokro (0.28).

4. Discussion

The decadal and 100-year daily rainfall isohyets developed in this study were compared with those currently used for the sizing of hydraulic structures in Ivory Coast, i.e. with those of [9, 2]. Figure 9 and 10 present the decadal isohyet maps of [2] and those of [9]. Next comes the 1931-2020 series map from this work (Figures 11). These isohyets are the 115 mm, 120 mm, 125 mm, 130 mm and 150 mm. The spatial distribution of these isohyets differs on each map. Those on the [9] map do not cover the whole country. They are more constricted in the South and go to the North, passing through the Center and the West. The isohyets of the [2] map are also constricted in the South and are more concentrated in the West. However, those of this present study occupy practically all the country. The 150 isohyet only covers the entire coastal strip on the [9, 2] maps, while it extends over part of the coastal strip (especially towards the South-East) on the map of this study. In addition, it includes part of the West on the map of the period 1931-2020. Note that the isohyet 120 could not be traced by the CIEH although it clearly appears in this present study and on the map of [2].

On the maps [2, 9], the 115 mm isohyet covers part of the South and approaches the North-East for that of [9] and the North-West for that of [2] passing through the center. Regarding the map of this study, this isohyet occurs in a small area in the East.

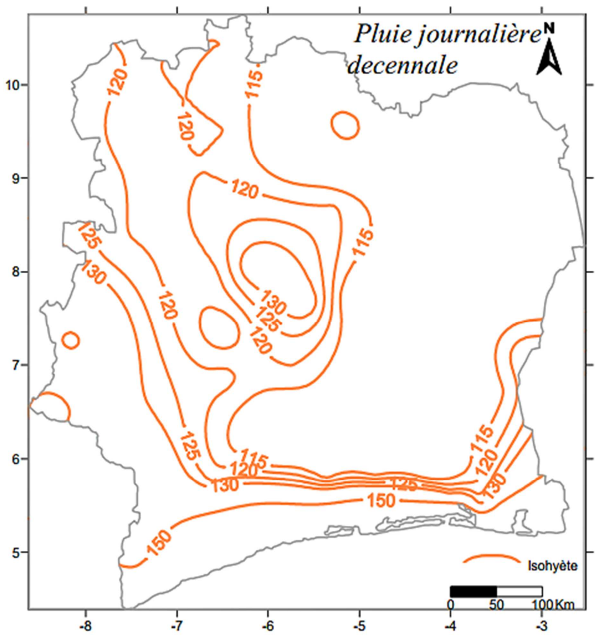

Figure 9. *Decadal daily rainfall isohyets from [2].*

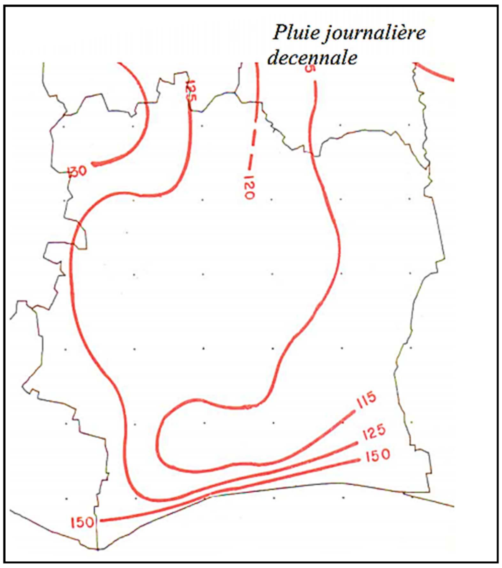

Figure 10. *Decadal daily rainfall isohyets from [9].*

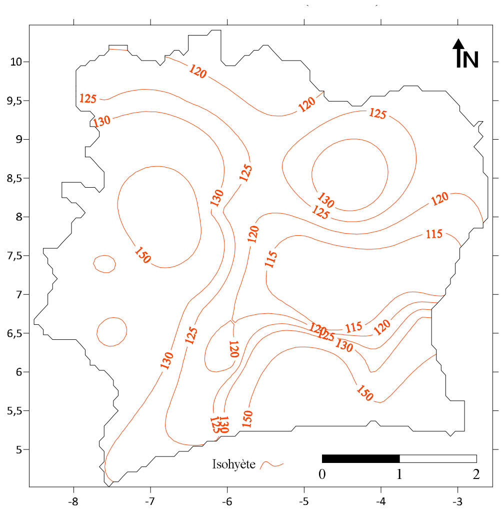

Figure 11. *Decadal daily rainfall isohyets of the present study (1931-2020).*

Figures 12, 13 and 14 show the spatial distribution of the specific isohyets of the centennial rains.

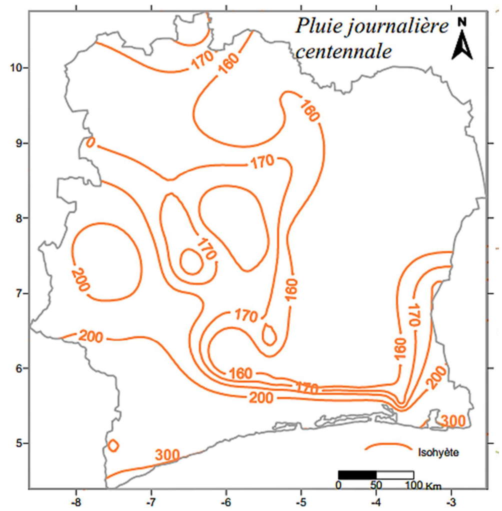

Figure 12. *Centennial daily rainfall isohyets from [2].*

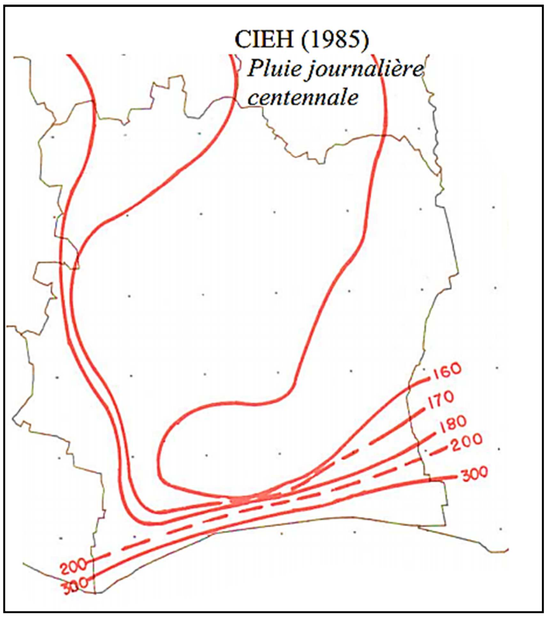

Figure 13. *Centennial daily rainfall isohyets from [9].*

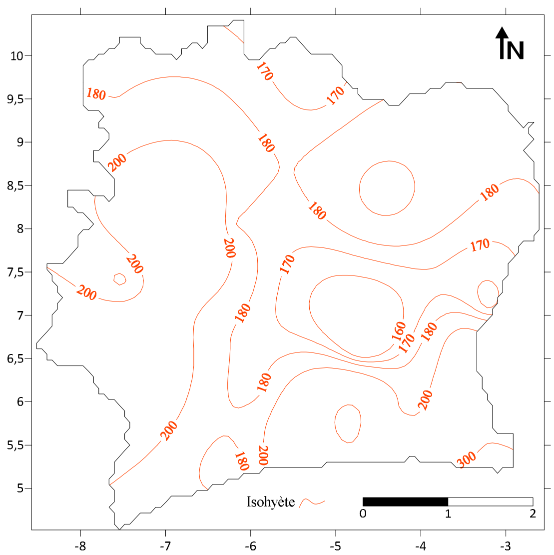

Figure 14. *Centennial daily rainfall isohyets of the present study (1931-2020).*

These isohyets are the 160 mm, 170 mm, 180 mm, 200 mm and 300 mm. The spatial distribution of these isohyets differs on each map. Their general appearance is almost the same as that of the ten-year rains at the level of all the maps. The 300 isohyet only covers the Tabou region on the [2] map and a small part of the Southeast, while it covers the entire coastal strip on the [9] map. The entire series map shows isohyet 300 over a tiny portion of the Southeast. However, the latter displays this isohyet in the Northwest and in a tiny part of the Northeast. The isohyet 200 which surrounds the mountainous region of Man on the map of [2], does not appear at the level of the map proposed by the [9]. But, it is very extensive over the entire territory on the maps of this study. Regarding isohyet 160, it is present in a restricted way on the map of this study. On the other hand, it appears and extends widely from South to North on the maps of [2, 9].

5. Conclusion

The objective of this study was to update the parameters of the ORSTOM and CIEH methods. These are annual rainfall normals, extreme rainfall norms, extreme rainfall quantiles as well as the extreme rainfall gradex.

The annual rainfall normals evaluated over the period 1931-2020 vary between 1,180.41 mm (Agnibilékro) and 1,878.01 mm (Abidjan) with an average of 1,457.4 mm. As for the normals of the annual maximum daily rains evaluated over the period 1931-2020, they oscillate between 73.61 mm (Agnibilékro) and 136.59 mm (Taboo) with an average of 94.57mm.

The 10-year return period quantiles evaluated over the period 1931-2020 vary between 103 mm (Dimbokro) and 222 mm (Tiassalé) with an average of 143.6mm. As for the centennial quantiles, they oscillate between 132 mm (Dimbokro) and 326 mm (Tiassalé) with an average of 211.5mm.

An analysis of the gradex based on the quantiles of the return period of 10 years and 100 years in Ivory Coast, revealed fluctuating values 0.28 (Dimbokro) between and 0.71 (Guiglo) with an average of 0.47 on Ivorian territory. The values of the standard deviation (0.09) and of the coefficient of variation (18.69%) show a homogeneity of the values of the coefficient of gradex.

A comparison of the local values obtained with the regional one proposed by ORSTOM and CIEH (0.38) was carried out. The gradex coefficients determined are all greater than the regional value of 0.38 defined by ORSTOM except for the Dimbokro station (0.28). Indeed, the calculated gradex coefficient biases are all positive (ranging from +2.63 to + 86.84%) except that of Dimbokro (-26.32%). The use of the regional value of 0.38 reflects an under designing of the values of the gradex coefficient for the whole country except the Dimbokro station. The gradex generally used for the calculation of design flow rates must be reviewed. Considering the entire series (1931-2020), we get closer to reality. In fact, the values of the gradex coefficient obtained at the end of this study vary across the country. The values generally used for the gradex coefficient are of the order of 0.45 for the Sahelian zones and 0.38 for the tropical zones. Considering the effects of climate change, these values have therefore become obsolete.

The results obtained during this work on the annual and extreme rainfall norms as well as the annual maximum daily rainfall quantiles and the extreme rainfall gradex constitute basic elements for designers and engineers in determining the project flows for the sizing of hydraulic structures in Ivory Coast. These estimated standards constitute an important decision-making tool in the process of researching strategies to combat hydroclimatic risks in general and floods in particular in Ivory Coast. This study revealed the obsolescence of the empirical methods of ORSTOM and CIEH very often used in the sizing of hydraulic structures.

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