ANALYSIS OF ANNUAL RAINFALL SERIES IN IVORY COAST IN ORDER TO DETECT CLIMATIC VARIATIONS

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ABSTRACT

Countries around the Guinea Gulf seem to have undergone climatic variations since the beginning of the 1970's.
The objective of the research programme Iccare (Identification et Conséquences d'une variabilité du Climat en AfRique de l'ouest non sahElienne) is to identify these climatic changes by analyzing rainfall and hydrometric time series homogeneity.
This paper presents the results of graphical methods and statistical tests performed to study annual rainfall series in Ivory Coast. They conclude that a rainfall deficit has been occurring for the last twenty-five years in the country.

1. INTRODUCTION

Drought that has been rampant in West Africa for about twenty years often has tragic effects in sahelian countries. This situation explains and justifies why many researchers have been focusing their interest on these regions. However the more southern countries around the Guinea Gulf, too, seem to have undergone climatic variations over the same period of time. Changes in rainfall and flow regimes may negatively interfere with agriculture development projects and with the management of water resources even in these generally wet regions. Consequently studies must be undertaken to characterize these changes.

This paper presents the first steps and results of the research programme named Iccare (Identification et Conséquences d'une variabilité du Climat en AfRique de l'ouest non sahElienne) (Servat, 1994). This programme is part of the FRIEND-AOC Project, and attempts to identify an *a priori* change in rainfall and hydrometric time series in wet West Africa.

The different symptoms of a climatic change are studied. Has rainfall been decreasing since the beginning of the 1960's ? Have the isohyets been moving ? Is this change spatially uniform ? Has the rainy season been starting earlier or later ? Has the depth of precipitation over the year, undergone changes ?

The results presented here concern annual rainfall in Ivory Coast.

Climatic variations are generally pointed out using graphical approaches and statistical tests adapted to the study of time series homogeneity.

We present hereafter some applications of these various approaches.

2. DATA

Rainfall data are provided by the rainfall network of Ivory Coast. The oldest time series begin in 1920. Some rainfall stations are not taken into account because they were installed too recently, or they were removed too early, or they are not reliable enough (significant percentage of missing values).

Twenty-six annual rainfall series beginning before 1950 are statistically analyzed.

Data are considered to be reliable until at least 1980, having been checked by C. I. E. H (Comité Interafricain d'Etudes Hydrauliques), and Orstom up to then.

3. RAINFALL REGIMES IN IVORY COAST

The studied stations cover the whole country with non-uniform density. However they are able to represent the spatial variability of annual rainfall (see Figure 1). The mean annual precipitation varies between 2400 mm (extreme south-west) and 950 mm (extreme north-east). The shape of the interannual isohyets is a U which is bowed towards the north-east. Their axis is a line which crosses Ivory Coast through Tabou (station 2-1), Gagnoa (station 6-5) and the east of Béoumi (station 5-3) . Rainfall regularly decreases from the south-west to the north-east along this axis. It increases when going away from this axis towards the north-west as well as towards the south-east (Mott MacDonald, BCEOM, SOGREAH, Orstom, 1993).

Table 1. Classification of the stations

Station / Group	Period of observation	Identification in Figure 1
Group 1		
Abidjan	1938-1992	1-1
Adiaké	1945-1993	1-2
Lamé	1930-1984	1-3
Sassandra	1923-1993	1-4
Group 2		
Tabou	1935-1992	2-1
Group 3		
Man	1923-1992	3-1
Group 4		
Boundiali	1934-1992	4-1
Odienné	1933-1993	4-2
Group 5		
Abengourou	1920-1992	5-1
Agnibilékro	1945-1992	5-2
Béoumi	1940-1992	5-3
Bondoukou	1937-1980	5-4
Bongouanou	1948-1992	5-5
Bouna	1920-1980	5-6
Dimbokro	1922-1992	5-7
Katiola	1949-1991	5-8
M'Bahiakro	1945-1992	5-9
Group 6		
Adzopé	1945-1992	6-1
Bouaflé	1924-1992	6-2
Daloa	1920-1992	6-3
Divo	1946-1992	6-4
Gagnoa	1930-1993	6-5
Lakota	1945-1992	6-6
Oumé	1945-1992	6-7
Soubré	1940-1992	6-8
Tiassalé	~~1930 1982~~	6-9

A hierarchic classification procedure has been used to distribute the twenty-six series into six homogeneous groups. These groups correspond to the six commonly identified rainfall regimes in Ivory Coast, with respect to the amount of precipitation and to its seasonal distribution. This classification is presented in Table 1.

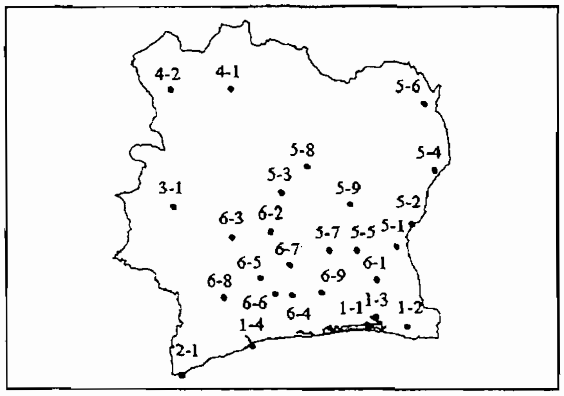

Figure 1. Location of rainfall stations in Ivory Coast

4. STATISTICAL PROCEDURES

Graphical methods are often used to give some insight into the homogeneity of time series. Some examples will be presented.

However it is always advisable to test the significance of departures from homogeneity by statistical methods. The different procedures used are briefly described in this section. They are drawn from the considerable amount of literature published on the general subject of the homogeneity of hydrological series (Lubès et *al*., 1994). They have been previously applied in other geographic contexts.

In the following, (x_i), i=1, N is the studied time series, $\bar{x}$ is its mean.

Pettitt's test (1979), derived from Mann-Whitney's is based on the properties of a rank statistic. The null hypothesis is homogeneity of the series.
It is supposed that for any time t between 1 and N, the time series (x_i), i = 1, t and (x_i), i = t+1, N belong both to the same population.
The tested variable is the maximum absolute value of the variable $U_{t,N}$ for t between 1 and N-1 :

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=t+1}^{N} D_{ij}$$

with $D_{ij} = \text{sgn}(x_i - x_j)$ and sgn(x) = 1 if x>0, 0 if x = 0, -1 if x<0.

If the null hypothesis is rejected, an estimate of the date of the change is given by the time t which provides the maximum absolute value of $U_{t,N}$.

Other tests, Statistic U (Buishand, 1982, 1984), Bayesian approach (Lee and Heghinian, 1977), amount to comparing means before and after an *a priori* supposed change. These tests are built on the following model :

$$x_i = \begin{cases} \mu + \varepsilon_i & i = 1, \dots\dots, \tau \\ \mu + \delta + \varepsilon_i & i = \tau + 1, \dots\dots, N \end{cases}$$

The ε_i's are independent random normal variables with zero means and common unknown variance σ^2. Parameters τ, μ, δ et σ are unknown and independent.
$1 \le \tau \le N-1, -\infty < \mu < \infty, -\infty < \delta < \infty, \sigma > 0.$

τ and δ are the time point and the amount of shift respectively.
If an *a priori* uniform distribution is supposed for the shift time τ, Buishand 's U statistic is defined by :

$$U = \left[N(N+1)\right]^{-1} \sum_{k=1}^{N-1} \left(S_k^* / D_x\right)^2 \quad \text{with}$$

$$S_k^* = \sum_{i=1}^{k} (x_i - \bar{x}) \quad \text{for k = 1,........., N and}$$

$$D_x{}^2 = N^{-1} \sum_{i=1}^{N} \left(x_i - \bar{x}\right)^2$$

The null hypothesis is homogeneity of the series. If it is rejected, this test does not propose an estimate for the time point of shift.

Lee and Heghinian' Bayesian method yields an estimate of the *a posteriori* probability distribution of the time point of shift.
When the distribution is unimodal, the mode is an estimate of the time point of shift. All the more reliable is this estimate as the distribution dispersion is low.

Hubert's procedure (Hubert et *al*, 1989) of series segmentation deals with the detection of several change points of the mean value. A specific algorithm provides one or more time points of shift which divide the series into different segments. Scheffé's test (Dagnélie, 1975) checks that the means of adjacent segments are significantly different.

Finally a confidence ellipse is used to analyze homogeneity of the series (x_i).

According to the model already presented, if the null hypothesis is true, the variable S_k^* has a normal distribution with zero mean and a variance estimated by :

$$k(N-k)\left(N-1\right)^{-1} D_x{}^2, k = 0, \dots\dots, N$$

Consequently for a given confidence threshold, it is possible to define a confidence ellipse which includes the series S_k^* if the null hypothesis is true. If the series is partly outside the ellipse, a shift can be considered as significant for the chosen confidence threshold.

5. INTERANNUAL ISOHYETS AND RAINFALL INDEX ANALYSIS

The stations have been used to define the interannual isohyets by decade since 1950 (Kouamé et *al*., 1994).
These graphs show that precipitation have been decreasing since 1970 over Ivory Coast. Figure 3 compares the decades 1950-59 and 1980-89.

Evolution of the 1200 mm isohyet shows that the zone receiving less than 1200 mm rainfall has been growing since the beginning of the 1970's. At the same time above 1700 mm zones have been narrowing. Nowadays the only region with such precipitation represents a narrow fringe close to Liberia.

To assess annual precipitation variations, Nicholson et *al*. (1988) defined a rainfall index. It is calculated every year over the 1950-1989 period by $\frac{x_i - \bar{x}}{s}$.

x_i is the precipitation for the ith year, $\bar{x}$ and s are the mean rainfall and the standard deviation over the 1950-1989 period, respectively.

Graphs of interannual rainfall indices conclude that rainfall has been decreasing since 1970 and more considerably since 1980. The Atlantic coast and the north, north-west part of the country are especially hit by the rainfall deficit. Figure 4 shows the maps for the decades 1950-59 and 1980-89.

6. RESULTS OF STATISTICAL PROCEDURES

Tests for detecting a shift in annual rainfall series have been used. The results are analyzed considering a regional point of view.

Table 2 presents the results. A shift is considered as a significant change in the mean of the series detected by all the procedures. When a change is not detected by all the procedures, it is called a "deviation".

The conclusions are the same as those of the graphical analyses with some more details.

A shift in the series mean has been detected in all regions excepted in the eastern part north of Bongouanou-Abengourou where rainfall is the lowest in Ivory Coast, and around Tabou in the south-west where rainfall is the highest in the country. In group 5 three stations only show a shift : Béoumi, Dimbokro and Katiola (see Table 1). In fact, these stations are close to the sixth zone where a general shift has been detected.

The shifts occurred at different time points, in the beginning of the 1960's at Béoumi for example, around the year 1980 at Abidjan, Adiaké and Odienné. Generally speaking they have been located from 1968 to 1975. This is in accordance with studies on sahelian regions.

A more definite conclusion is that a shift of the annual rainfall regime can clearly be identified. The dates of shift and the percentages of deficit with regard to the mean must be cautiously considered because they are not independent of the series duration.

Table 2. Results of statistical procedures

Station / Group	Time point of shift	Deficit expressed in % with regard to the mean before shift
Group 1		
Abidjan	1982	22
Adiaké	1982	25
Lamé	1968	24
Sassandra	1971	18
Group 2		
Tabou	no shift	
Group 3		
Man	1966 (deviation)	13
Group 4		
Boundiali	1975	20
Odienné	1979-1982	23
Group 5		
Abengourou	no shift	
Agnibilékro	no shift	
Béoumi	1963-1964	15
Bondoukou	no shift	
Bongouanou	no shift	
Bouna	no shift	
Dimbokro	1968	13
Katiola	1968	22
M'Bahiakro	no shift	
Group 6		
Adzopé	1968	15
Bouaflé	1972	18
Daloa	1971	16
Divo	1972	18
Gagnoa	1966	12
Lakota	1970	25
Oumé	1976-1979	17
Soubré	1970	21
Tiassalé	1969 (deviation)	17

7. STUDY OF VERY LONG TIME SERIES

The longest series (more than six decades) provide information on the intrinsic variability of the time series variable.
The shift that has previously been identified in these series can then be compared to other changes that occurred in the past.
Consequently the time series of rainfall indices can be used to define wet and dry periods according to the positive or negative values of the index, respectively. These values are considered to be significant with regard to the confidence interval of the mean at 95%. Each period is characterized by its duration and by a value taken as a linear combination of the annual indices, thereby representing the relative impact of the wet or dry period. All periods of the same type, i.e. wet or dry, can be compared by making a plot of impact indices against durations for this particular type.

Figure 2 shows the dry periods of the annual precipitation series of Bouaflé. Data begin in 1924. It can be observed that the last dry periods (since around 1970) are both the longest and the most severe at this station.
Since 1973, only years 1980 and 1985 have a positive index.
Before 1970 wet and dry periods generally lasted less than 3 years and followed one another.

Consequently the current deficit can be considered to be peculiar.

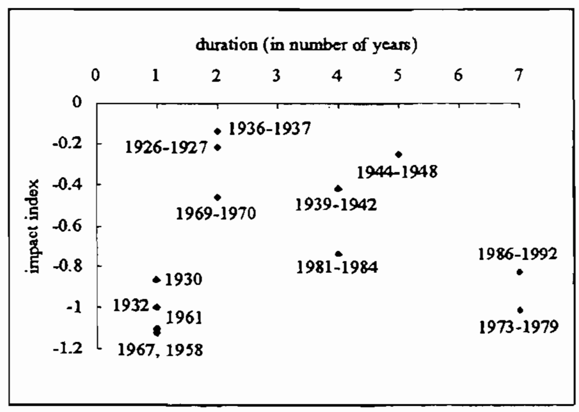

Figure 2. Dry periods of the annual precipitation series of Bouaflé

8. CONCLUSION

This study deals with annual rainfall series at different stations in Ivory Coast.

Graphics and statistical tests conclude that a rainfall deficit has been occurring for the last twenty-five years in 80% of the country. Most of the series reveal a change of mean between 1968 and 1975. These results are consistent with studies concerning sahelian regions.
The other countries of the Guinea Gulf, Ghana, Togo, Benin, are being studied in the same way. A first analysis of the interannual isohyets and indices graphs by decade already reveal that the rainfall deficit has been extending in these countries since the beginning of the 1970's. The same kind of studies will be conducted in the other countries of non-sahelian West Africa. They will confirm or not the climatic variability hypothesis with a large geographic extent in this part of Africa.

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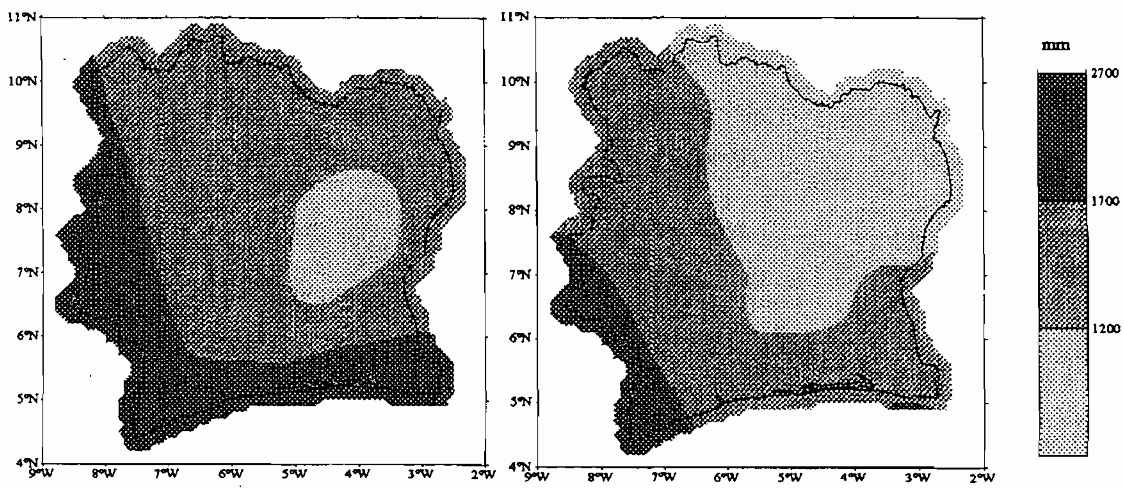

Figure 3. Interannual isohyets over the decades 1950-59 (left) and 1980-89 (right)

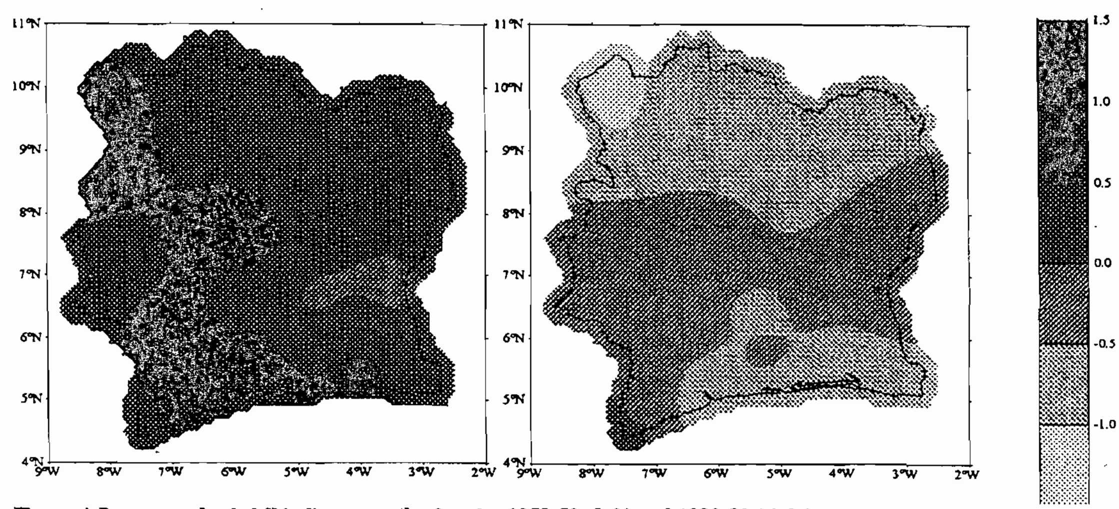

Figure 4. Interannual rainfall indices over the decades 1950-59 (left) and 1980-89 (right)

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Lubès Hélène, Paturel Jean-Emmanuel, Servat Eric, Masson J.M., Kouamé Brou.

Analysis of annual rainfall series in Ivory Coast in order to detect climatic variations.

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