REDEFINITION OF HOMOGENEOUS CLIMATIC ZONES IN COTE D'IVOIRE IN A CONTEXT OF CLIMATE CHANGE

*KOUAKOU Koffi Eugene[1], MOUSSA Hassani[1], KOUASSI Amani Michel[1], GOULA Bi Tie Albert[2], SAVANE Issiaka[2]

Abstract
The study entitled " Redefinition of homogeneous climate zones in Côte d'Ivoire in a context of climate change " aims to update the division of Côte d'Ivoire's climate zones in the current context marked by disruptive effects of climate change. To achieve this, the representation of Gaussen ombrothermal diagrams and principal component analysis was used. The results identified three climatic regimes across the ivorian territory and grouped into four climatic regions.
A first zone of coastal and equatorial climate located in the South and bordering the Ivorian coast has a bimodal rainfall regime and comprises four seasons including two rainy seasons and two dry seasons.
A second region with an equatorial transition climate is located in the central part of the country. The precipitation regime is bimodal and involves a great rainy season and a long dry season
Then, comes a third zone corresponding to the wet and dry tropical climate located in the northern part of the country. The diet in this third climatic zone is unimodal with a long rainy season and a long dry season. Finally, it appears a fourth climatic region corresponds to the mountain climate. Its rainfall pattern is similar to that of the humid and dry tropical climate. Finally, it appears a fourth climatic region corresponds to a mountain climate. Its rainfall pattern is similar to that of the humid and dry tropical climate.
However, although the number of the four climatic regions is conserved at the end of our study, there are many divergences in their spatial extension and temporal variability.
In fact, the area defined by the coastal and equatorial climate has declined considerably in favor of the equatorial climate of transition and the humid and dry tropical climate respectively.

Index iterm: climatic zones, climates, redefinition, Ivory Coast, climate change

INTRODUCTION

Climate plays an important role in earth life. Indeed, natural resources (water, forest,) and economic activities and even humans depend in part on its variations. It is with its strong variable character and determining in the daily life that its control is a necessity.

In all the countries of the world, climatic zonings have been made to bring the agricultural world especially to enjoy the benefits of certain climatic variables such as temperature and precipitation.

It is for this reason that in West Africa, the study of climates has always been a concern for researchers whose research is fourfold.

In fact, the first group carried this research on knowledge of climates, seasons and their characteristics [1, 2, 3, 4].

The second group of researchers [5, 6, 7, 8, 9, 10, 11, 12] focuses on the study of climate variability and its impacts on water resources.

The third category of researchers converges their efforts on understanding the mechanisms that cause climatic variations [13, 14, 15, 16, 17, 18].

Finally, the last batch of researchers is studying the modeling of West African climates in a perspective of climate prediction for the 21st century through global climate models [9, 10, 19, 20, 21] and regional climate models [18] ; [22, 23, 24, 25, 26].

These studies have shown that West African climates are undergoing disturbances of climate change. Indeed, there are decreases in precipitation, late starts and early endings of precipitation and rising temperatures. This situation of unstable rainfall is hampering farmers

Indeed, in several African countries in general, and in Côte d'Ivoire in particular, agriculture is one of the most important sectors of the Ivorian economy. It plays a crucial role in the country's economic development and still contributes significantly to gross domestic product (GDP) as in many African countries. Climate is the primary determinant of agricultural productivity and has a major influence on food production and the economy as a whole.

Similarly, [27] have shown that agriculture in West Africa, vital to the local population, is extremely dependent on the rainy season and requires a good understanding of the seasonal cycle of rainfall. Indeed, the populations of these countries are predominantly rural and operate production systems whose performance is closely linked to climate [28]. In this context, the impact of climate change on rainfall regimes and agriculture is a subject of great importance, and has already motivated a relatively abundant literature [29].

In Côte d'Ivoire, hydroclimatic classifications and climatic zonings have already been proposed at the national level [1, 2, 3, 4].

However, these classifications present weaknesses today because the study periods are outdated and no longer suitable for the current context marked by climate change. In addition, the number of climatic parameters used is insufficient even when the period of the study is recent. For all these reasons, we add the methodologies used which differ from one study to another. It is for all these reasons that this study proposes to redefine homogeneous climatic zones in a context of climate change by correcting the shortcomings of the previous studies but also based on new methods of classification of climates

1. MATERIAL AND METHOD

This paragraph develops all the data and methods used for the redefinition of climatic regions in Côte d'Ivoire

1.1. Material

The material used consists essentially of climatic data plus statistical processing tools

1.1.1. Study data

Classification of climatic zones has been possible thanks to temporal characterization and spatial characterization of climates.

For the temporal characterization, the data used are the daily rainfall and the decadal temperatures from 1980 to 2000 of the various rainfall stations and synoptic stations of Côte d'Ivoire.

For spatial distribution, the annual values of climatic parameters of the fourteen synoptic stations of Côte d'Ivoire were used. These are relative humidity, precipitation, temperature, insolation, wind speed, potential evapotranspiration (PET), latitude and altitude of rainfall stations, pressure, number of rainy days, temperature and temperature range.

These data were provided by the Airport Exploitation and Development Company, Aeronautics and Meteorology (SODEXAM) which is the main manager of the network and climate data in Côte d'Ivoire.

The choice of the different climatic and rainfall stations as well as the period of the study was guided by the need to have good quality data over a long period but also to obtain the most homogeneous coverage possible throughout the country. Figure 1 shows the nature and spatial distribution of these stations.

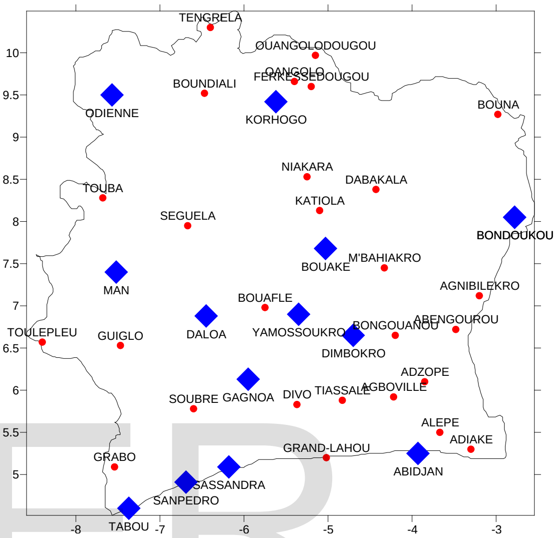

Figure 1: Location of the synoptic and rainfall stations studied

Caption: in blue: synoptic stations; in red: rainfall stations

1.2.1. Informatics tools

Data processing for this study was done using software such as:

- Microsoft Excel 2013 for the realization of various calculations, tables and graphs;
- XLSTAT 2017 for conducting a principal component analysis from a matrix of data on the variables characteristic of the synoptic stations in order to determine the relationships between the variables and / or the opposition between the individuals;
- Surfer 8.02: for the division of the different homogeneous climatic zones and the realization of the different thematic maps of the study.

1.2. Methods

1.2.1. Characterization of the variability of the annual climate cycle

The temporal variability of the annual cycle of the climate was done using the ombrothermic diagram or diagram of [30]. This diagram makes it possible to define, for each station, the rainy and dry seasons, based on the comparison of monthly average temperatures (T in ° C) with those of precipitation (P in mm).

The principle of this method is to represent on the same graph the temperature and the pluviometry in ordinate for the 12 months of the year in abscissa. The scales taken on the ordinate are such that 1 ° C corresponds to 2 mm of precipitation. Thus, according to [31], a month is dry when "P is less than or equal to 2T". Conversely, when "P is greater than 2T", the month is considered wet.

For [32] and [33], a period is wet when the precipitation curve passes above the temperature curve and a period is dry in the opposite case. This diagram also shows the evolution of the temperatures and the precipitation regime

1.2.2. Climate Regionalization by Principal Components Analysis

Principal component analysis (PCA) is probably the most widely used multivariate statistical technique in the atmospheric sciences [34, 35]. The goal of this technique is to transform a database containing a large number of variables into one that contains only a small number of new variables, while retaining much of the original variability [36]. This facilitates the identification of factors that may explain a phenomenon. In addition, the principal components analysis makes it possible to eliminate any correlation between components, which represents a significant advantage in climatology, where one is often faced with a situation of collinearity [37].

These new variables are called "principal components" or main axes. It makes it possible to visualize synthetically a set of quantitative variables measured on a set of individuals, and to see how individuals position themselves in the links between these variables. In addition, it can help to determine the factors that influence their spatial variability.

The analysis of the data thus essentially aims to describe the links between the variables and the observations of our matrix of data, this matrix consists of p dimensions and N individuals.

The selection of variables plays an important role in data preprocessing because it allows to eliminate from the correlation matrix after a first simulation the variables that are not representative (correlation <0.5). Only indices with strong contributions will be used for further analysis. For this, we selected eighteen (18) relevant variables observed at the annual time step on 14 synoptic stations (Figure. 1). These include precipitation, temperature, insolation, humidity (minimum, average and maximum), number of rainy days, pressure, wind speed, rain (minimum, and maximum), and number of dry months, evapotranspiration and thermal amplitude. To these climatic parameters, other parameters such as latitude, altitude and longitude have been added. These parameters will be reduced gradually after simulation to remain only the most significant.

The processing of the PCA data was done with the XLSTAT 2017 software.

2. RESULTS AND DISCUSSION

2.1 Characterization of the temporal variability of the seasons

The construction of the ombrothermic diagrams made it possible to distinguish three climate regimes in Côte d'Ivoire. These are, respectively, the unimodal rainfall regime (North), bimodal at two seasons (Center) and bimodal at four seasons (South).

2.1.1. Two-season unimodal rainfall regime

The unimodal regime is located in the northern part of the Ivory Coast (Figure 2). It covers localities us Bouna, Ferkessedougou, Ouangolo, Korhogo, Boundiali, Seguela Tengrela, Odienné. The seasonal evolution of precipitation in this zone makes it possible to distinguish two very contrasting seasons, one of which is dry and the other humid. The dry season is longer with an average duration of five months, or about 150 days. It occurs from November to March and is very sparsely watered with average monthly rainfall in the order of 13.46 mm.

As for the rainy season, it lasts on average seven months or 210 days. It starts in mid-March or even April and ends in the course of October. The maximum water levels are reached in August for all stations except the station of Ferkessédougou which has its maximum rainfall in September.

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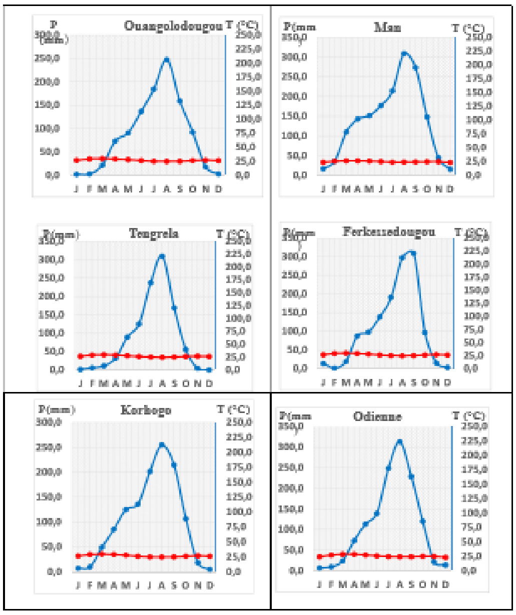

Figure 2: Ombrothermal curves showing the unimodal rainfall regime in some localities of northern Côte d'Ivoire

2.1.2. Four-season bimodal rainfall regime

The second group of rainfall stations is composed of Abidjan, Adiake, Sassandra, San Pedro, Grand Lahou, Agboville, Adzope, Tiassale and Dabou stations (Figure 3).

The latter have a bimodal rainfall pattern characterized by two dry seasons and two distinct rainy seasons.

In the rainy seasons, the first usually starts in mid-February and ends in late July and lasts 5 months overall. The second rainy season is shorter and lasts 3 months (September, October, and November).

The rainy seasons are separated by two dry seasons, the largest of which starts in December and ends in February, ie three months. The short dry season called inter-season is very short centered on the month of August. However, whether it is the rainy seasons or the dry seasons, their durations vary according to the localities.

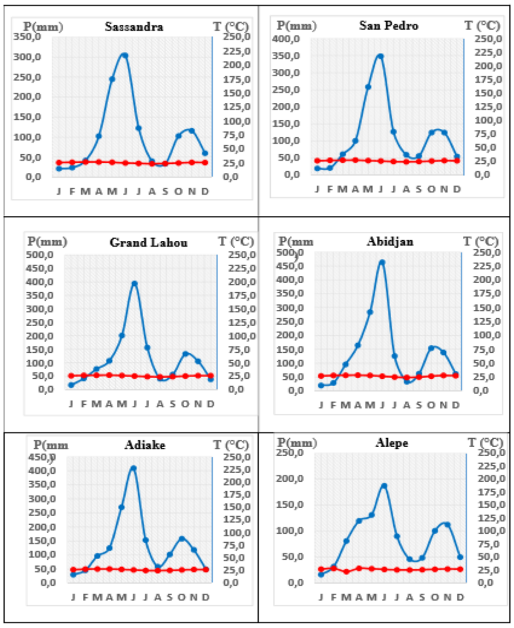

Figure 3: Ombrothermal curves showing the unimodal rainfall regime in some localities of southern Côte d'Ivoire

2.1.3. Two-season bimodal rainfall regime

Between these first two sets is inserted a third group of rainfall stations whose seasonal evolution of rainfall has a bi-modal trend. These are the Yamoussoukro, Dimbokro, Bondoukou, Gagnoa, Daloa, Bouake, Katiola, Abengourou, Agnibilekro, Dabakala, M'bahiakro, and Bongouanou stations

In fact, precipitation curves are bimodal in a single, large rainy season that usually starts in early March and ends in November. It lasts on average 8 months with a slight depression in July-August. The analysis of the precipitation curve reveals two peaks, the first in June and the second in September with a decrease in precipitation in August which gives it the character of a bimodal regime. However, in the plot of ombrothermal curves, that of precipitation remains above the temperature curve since the beginning of the rainy season until its end. Thus, the month of August cannot be qualified as a dry month despite the decrease in rainfall.

As for the dry season, it lasts about three months, from the beginning of December to the end of February.

However, within this transitional climatic zone, there are variations in rainfall patterns, in the amount of water precipitated and in the duration of the seasons, depending on whether or not the locality is close to one of the first two climatic zones.

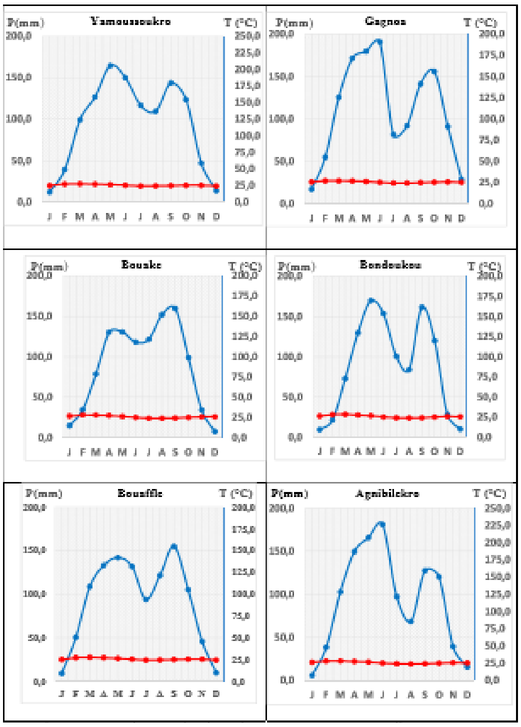

Figure 4: Ombrothermal curves showing unimodal rainfall in a few localities in central Côte d'Ivoire

2.2. Regionalization of climatic parameters by principal component analysis

At the end of the temporal distribution of the seasons in Côte d'Ivoire, it is important to know the localities whose climatic parameters have affinities or zones whose spatial variation of climatic parameters is identical.

For this purpose, the principal components analysis was used. It allowed us not only to define the factorial axes or factors responsible for this distribution and, therefore, to highlight the affinities between the different stations with a view to reconstructing their spatial distribution.

2.2.1. Analysis of eigenvalues

Table 1 expresses the eigenvalues of the matrix of correlation coefficients, the percentage of variance explained as well as the cumulative variance of each axis. Thus, the results of principal component analysis (PCA) reveal that the first three components explain 84.73% of the total variance, with 55.52% for the first axis, 17.92% for the second, and 11.27% for the third axis. Thus, these three axes were taken into account because according to the Kaiser rule, the eigenvalues greater than the mean of the eigenvalues of the eleven factorial axes are retained. This average is 1 in the case of this study.

Table 1: Characteristic values of the three selected factorial axes

	F1	F2	F3
eigenvalues	6,11	1,97	1,24
Variability (%)	55,54	17,92	11,27
% cumulated	55,54	73,46	84,73

2.2.2. Climate regionalization using principal component analysis

This representation is intended to provide approximate flat images of the cloud of stations (individuals) located in the factorial plane. Before the regrouping of the stations, it was highlighted the climatic variables which characterize the climatic stations of Côte d'Ivoire (Figure 5).

Thus, Korhogo and Odienné stations located on the positive part of axis I are characterized by parameters such as annual insolation (an.I), latitude, thermal amplitude (TA), potential evapotranspiration (PET) and altitude. On the negative part of axis 1, climatic variables influencing the stations (Abidjan, San Pedro, Tabou Adiake) are pressure, relative humidity (Hr) and annual rainfall (AR) and number of rainy days (Nbrd).

At axis 2, the Dimbokro station is characterized by high values of average temperature (Tm) and high wind speed (Wsp) while on its negative part, the stations of Gagnoa, Man and Daloa are weakly correlated by low mean temperatures (Tm), low wind speed (Lwsp) and significant numbers of rainy days.

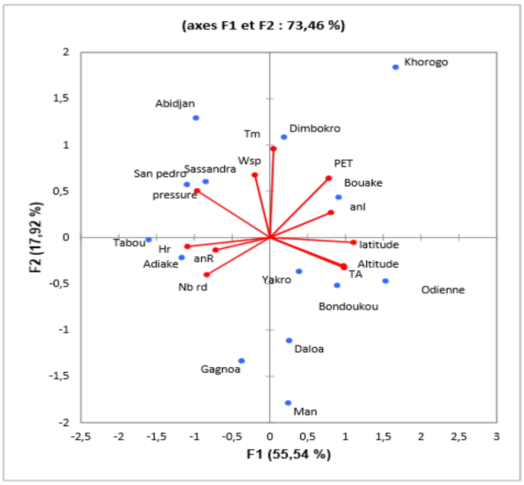

Figure 5: Relationship between climate variables and weather stations in Côte d'Ivoire

After linking climatic variables and climatic stations, it is important to group climate stations with similar climatic characteristics.

Thus, the factorial plane I-II makes it possible to distinguish three groups of stations (Figure 6).

Indeed, the axis I of this factorial plan opposes the stations located in the south of Ivory Coast (Abidjan, Sassandra, Adiake, San Pedro, Tabou) to those of the North notably the stations of Khorogo, Odienné, Bouaké and Bondoukou.

Stations in the South are characterized by high relative humidity values, large numbers of rainy days and high pressures. On the other hand, those of the North are rather influenced by high thermal amplitudes, low relative humidity, latitude and annual insolation.

Axis II also makes it possible to distinguish two types of stations. These are the resorts located in central Côte d'Ivoire. These are the Man, Daloa and Gagnoa stations characterized by significant numbers of rainy days, low average temperatures, and low wind speeds. The Dimbokro station is influenced by high average temperatures and low numbers of annual rainy days.

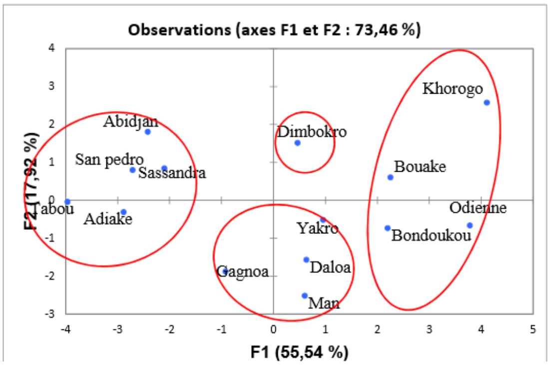

Figure 6: Projection of parameters on factorial plane I and II

At the level of the factorial plane I-III (Figure 7), axis I keeps the structure similar to plane I and II except that the Bondoukou station deviates from this axis.

Regarding Axis III, it opposes the stations of Daloa, Gagnoa, Yamoussoukro, Bondoukou, Dimbokro to that of Man. In fact, the first groups of stations in axis III are characterized by low values of annual rainfall, insolation, number of rainy days and wind speed. The isolation of the Man station is explained by the fact that this station is strongly correlated with the lowest temperatures and also by the relatively large number of rainy days like the stations of the South of the country.

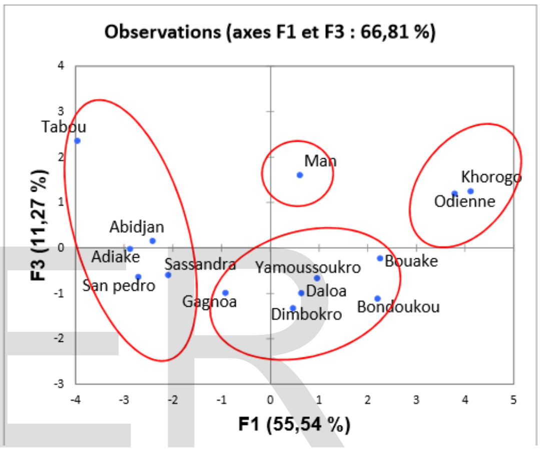

Figure 7: Projection of parameters on factorial plane I and II

In the factorial F2-F3 (Figure 8), the distribution of individuals is much more confused because there is no significant correlation between the variables and the factorial axis III. Moreover, the low percentage of inertia of the factorial plane F1 and F2 (29, 2) explains this situation. Indeed, the minimum average required for a better interpretation is 50%.

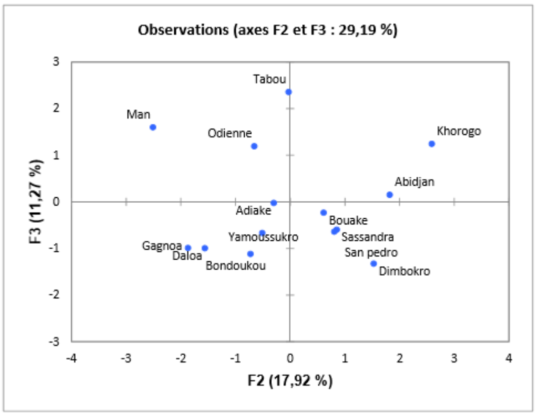

Figure 8: Projection of parameters on factorial plane II and III

2.3. Distribution of climatic regions of Côte d'Ivoire

This section combines both the results of the principal component analysis and Gaussen ombrothermal diagrams. Indeed, the ombrothermic diagrams have highlighted three climatic regimes in Côte d'Ivoire and makes it possible to obtain three climatic regions. In addition, the application of PCA has identified the same climatic zones but also to distinguish a zone particularly influenced by the relief corresponding to the region of Man.

The synthesis of the different results made it possible to obtain the climatic zoning of Côte d'Ivoire presented in figure 9.

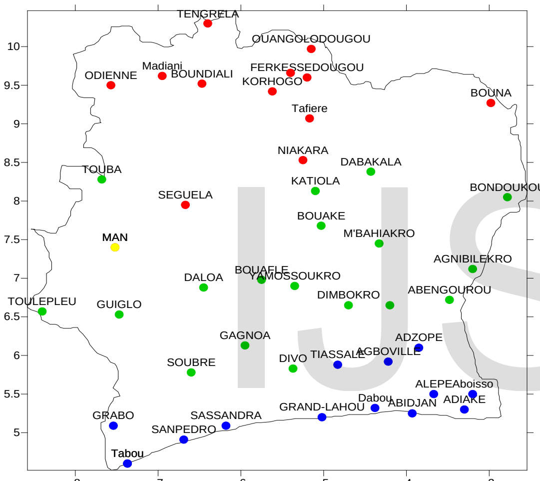

Figure 9: Presentation of the climatic regions of Côte d'Ivoire

Legend: orange: Sudanese climate dry and wet; green: equatorial transition climate; blue: coastal and equatorial climate; yellow: mountain

Using Figure 9, a climatic zoning of the Ivory Coast carried out thus obtaining four homogeneous climatic regions in the current context influenced by the climatic changes (figure 10).

Thus, we can distinguish the humid and dry tropical climate, the equatorial transition climate, the coastal and equatorial climate and the mountain climate. The characteristic parameters of each climate zone are shown in Table 2 below.

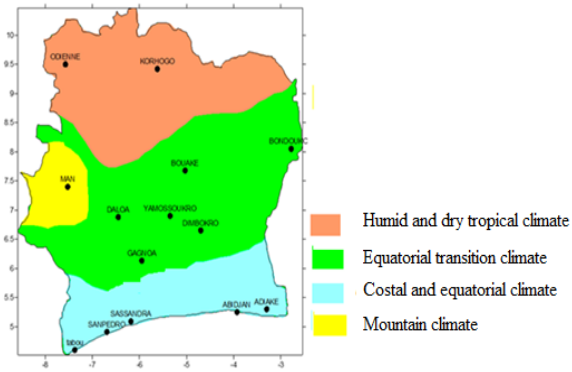

Figure 10: Updated climate zoning of Côte d'Ivoire

Table 2: Characteristic parameters of climatic regions of Côte d'Ivoire

Climats	Régime climatique	Pluviométrie annuelle (mm)	Humidité relative (%)	Durée de la saison des pluies (mois)	Température annuelle (°C)	Température Min - Max annuelle (°C)	Insolation Annuelle (heures)	Durée de la grande saison sèche	Paramètres caractéristiques
Climat tropical humide et sec	Unimodal à 2 saisons	992 - 1383	62-67	7-8	26-27	20 -35	2437-2680	4-5	Amplitude thermique, Insolation annuelle, ETP, Altitude, Latitude
Climat équatorial de transition	Bimodal à 2 saisons	942-1625	70-80	9-11	26-27	20 -33	1947-2127	1-3	Nombre de jours de pluie, température moyenne
Climat côtier et équatorial	Bimodal à 4 saisons	1016-2238	83-85	5-6	26-27	22-24	1772-2179	2-3	Humidité moyenne relative, Hmax, Hmin, pluie annuelle, nombre de jours de pluies, Pression
Climat de montagne	Unimodal à 2 saisons	1636-1806	76	8-9	25	20 -31	2301,2	3-4	Nombre de jours de pluies, pluie annuelle

2.2. Discussion

The study of the redefinition of Côte d'Ivoire's climatic zones covered both the temporal and spatial variability of climatic regimes and climatic zoning of Côte d'Ivoire.

With regard to the temporal variability of the seasons and their regime, the realization of the ombrothermic curves made it possible to distinguish three climatic regions over the whole country. The first climatic region is located in North-West.

This climatic zone has a unimodal rainfall pattern and has a dry season and an average rainy season of 5 and 7 months, respectively.

Indeed, the dry season usually starts at the beginning of November and ends at the end of March. The rainy season begins in the course of April and stops at the end of October. The second climatic region is located in the south of the country and extends from east to west along the coast. It also shows a well-marked four-season bimodal rainfall regime, two of which are wet and two dry. It brings together Côte d'Ivoire resorts. Between these two major zones is a third zone, which corresponds to a transition zone whose regime is bimodal but includes a rainy season and a dry season. In view of these results, there are common features and divergences with earlier work by [1, 2, 3, 4]. Indeed, all have shown that there are three climatic regimes in Côte d'Ivoire.

The difference is in the spatial boundaries of each climate zone, the length of the seasons, the number of seasons, and the amount of rainfall that has fallen. These various results are justified by the fact that the periods of study and the methodologies used are different.

[1], based on water deficits from 1950 to 1966, and the distribution of vegetation in Côte d'Ivoire, identified a transition zone with a bimodal precipitation regime with 2-4 seasons in the year the localities then we found two. This reduction of seasons from 4 to 2 in some localities related to the combined effect of variability and climate change as meant in several studies [9, 38]. Moreover the geographical limits of this one of the different zones have strongly changed. These changes are logical because the two periods of study are located at the other and of the year 1970 which is the pivotal year of the climatic breaks in West Africa and in Ivory Coast in particular.

According to several studies on climate variability in West Africa, the period before 1971 was wetter and the one after is dry [1, 6, 7, 8, 9, 11, 38].

For [3], the period of study is 1950-1997 and includes the study period of [1] and ours. To this end, he finds three rainfall regimes whose boundaries are different from those of [1] and the limits found in this study.

As for [4], they determine four climate zones with only two climatic regimes, one of which is four seasons and the other two seasons.

In Côte d'Ivoire's climatic zoning related to precipitation regimes, this study has associated the main component analysis, which involved eleven climatic parameters (annual rainfall, wind speed, latitude, altitude, relative humidity, annual insolation, temperature, pressure number of days of rain, potential evapotranspiration and temperature range.

The cross analysis of the different factorial axes of the principal component analysis (PCA) allowed to identify four climatic regions, three of which are consistent with the climatic regimes already identified, and a mountain climate in the western part of Côte d'Ivoire characterized by parameters such as altitude, humidity and temperature.

The cross analysis of the different factorial axes of the principal component analysis allowed to identify four climatic regions, three of which are consistent with the climatic regimes already identified, and a mountain climate in the western part of Côte d'Ivoire characterized by parameters such as altitude, humidity and temperature.

5. CONCLUSION

The study entitled "redefinition of homogeneous climatic zones in Côte d'Ivoire in a context of climate change" aimed to propose a new division of Côte d'Ivoire into climatic regions following the upheaval of climates in the world particularly west. Based on the Gaussen ombrothermal diagrams of the Principal Component Analysis of 12 climatic parameters, four climatic regions were found. A coastal and equatorial climate located to the south and bordering the Ivorian coast has a four-season bimodal rainfall regime including two rainy seasons and two dry seasons. A second region with an equatorial transition climate is located in the central part of the country. The precipitation regime is bimodal and involves a great rainy season and a long dry season. Then comes a third zone corresponding to the wet and dry tropical climate located in the northern part of the country whose rainfall is unimodal with a long rainy season and a long dry season. Finally, the fourth climatic region corresponds to the mountain climate and is similar from the point of view of the precipitation regime to humid and dry climate. However, although the number of the four climatic regions is conserved at the end of our study, there are many discrepancies both in terms of spatial extension and their temporal and regime variability. This study has therefore made a significant contribution to the knowledge of the spatial and temporal distribution of the Côte d'Ivoire's homogeneous climatic zones and constitutes for this purpose an important tool for the agricultural world, which still depends on the climate.

REFERENCES

[1]- M. Eldin, “le climat. In ‘le milieu naturel de la Côte d’Ivoire’. Mémoire ORSTOM,” 50, Paris, pp. 76-108, 1971.

[2]- G. Riou, “Proposition pour une géographie des climats en Côte d’Ivoire et au Burkina Faso. Le climat de la savane de Lamto (Côte d’Ivoire) et sa place dans les climats de l’Ouest Africain,” Lamotte M. et Tirefords J.L, “Travaux des chercheurs de Lamto”, pp 81-115, 1988.

[3]- S. Bigot, “Variabilité climatique, interactions et modifications environnementales : l’exemple de la Côte d’Ivoire, Mémoire pour l’Habilitation à Diriger des Recherches en géographie,” CNRS UMR 8141, 2004.

[4]- B. T. A. Goula, B. Srohourou, A.B. Brida, K.A. N'zué, G. Goroza, "Zoning of rainfall in Côte d'Ivoire," *International Journal of Engineering Sciences and Technology,* 2 (11), pp 6004-6015, 2010.

[5]- S. Janicot, "Variabilité des précipitations en Afrique de l'Ouest et circulation quasi-stationnaire durant une phase de transition climatique. 1ère partie – synthèse," *Thèse de doctorat*, Université Paris VI, France, 1990.

[6]- S. Janicot, B. Fontaine, "Evolution saisonnière des corrélations entre précipitations en Afrique guinéenne et température de surface de la mer (1945-1994)," *Géophysique erxterne, Climat et Environnement, 32 (2a), pp. 785-792,* 1997.

[7]- E. Servat, J. E. Paturel, H. Lubès, B. Kouamé, M. Ouedraogo et J. M. Masson, "Climatic variability in humid Africa along the Gulf of Guinea. Part I: detailed analysis of the phenomenon in Côte d'Ivoire," *Journal of Hydrology*, 191, 1-15, 1 pp. 997.

[8]- G. Mahé, Y. L'Hôte, J. C. Olivry, G. Wotling, "Trends and discontinuities in regional rainfall of West and Central Africa (1951-1989)," *Hydrological Sciences Journal*, 46 (2), pp. 211-226, 2001.

[9]- B. S. Ardoin, "Variabilité hydroclimatique et impacts sur les ressources en eau de grands bassins hydrographiques en zone soudano-sahélienne," *Thèse de Doctorat de l'Université de Montpellier II*, 2004.

[10]- B. T. A. Goula, I. Savane, B. Konan, V. Fadika, V. Fadika, G. B. Kouadio, "Impact de la variabilité climatique sur les ressources hydriques des bassins de N'Zo et N'Zi en Côte d'Ivoire (Afrique tropicale humide)," *Vertigo*, 7 (1), pp. 1-12, 2006.

[11]- K. E. Kouakou, B. T. A. Goula, I. Savané, "Impacts de la variabilité climatique sur les ressources en eau de surface en zone tropicale humide : Cas du bassin versant transfrontalier de la Comoé (Côte d'Ivoire - Burkina Faso)," *European Journal of Scientific Research*, 16 (1), pp. 31-43, 2007.

[12]- A. M. Kouassi, K. F. Kouamé, M. B. Saley, Y. B. Koffi, "Identificatin of trends in the rainfall runoff relation and refill of the aquifers in a hydroclimatic context: case study of the N'zi (Bandama) catchment in Ivory Cost," *European Journal of Scientific Research*, 16 (3), pp. 412-428, 2007.

[13]- P. J. Lamb, "Persistence of Sub-Saharan Drought, *Nature*," 299, pp. 46-47, 1982.

[14]- P. J. Lamb, R. A. Peppler, "Further case studies of tropical atlantic surface atmospheric and oceanic patterns associated with sub-saharan drought," *Journal of Climate,* 5 (5), pp.476-488, 1992.

[15]- S. Janicot, A. Harzallah, B. Fontaine, V. Moron, "West African monsoon dynamics and Eastern Equatorial Atlantic/Pacific SST anomalies (1970-1988)," *Journal of Climate*, 11, 1874-1882, 1998.

[16]- B. Fontaine, S. Janicot, P. Roucou, "Coupled ocean-atmosphere surface variability and its climate impacts in the tropical Atlantic region," *Climate Dynamic,* 15, pp. 73, 1999.

[17]- Y. Kouadio , D. A. Ochou, J. Servain, Atlantic influence on the rainfall variability in Côte d'Ivoire," *Geophysical Research Letters*, 30, pp. 8005-8012, 2002.

[18]- R. Ramel, "Impact des processus de surface sur le climat en Afrique de l'Ouest," *Thèse de doctorat de l'Université Joseph Fourier de Grenoble*, France, 2005.

[19]- D. Sighomnou, "Analyse et redéfinition des régimes climatiques et Hydrologiques du Cameroun : perspectives d'évolution des ressources en eau," *Thèse de Doctorat d'Etat Université de Yaoundé 1*, Cameroun, 2004.

[20]- A. Giannini, R. Saravanan, P. Chang, "Dynamics of the boreal summer African monsoon in the NSIPP1 atmospheric model," *Climate Dynamics*, 25, pp. 517-535, 2005.

[21]- M. Joly, A. Voldoire, H. Douville, P. Terray, J. F. Royer, "African monsoon teleconnections with tropical SSTs: validation and evolution in a set of IPCC4 simulations," *Climate Dynamic*, 382 (6), pp. 215-218, 2007.

[22]- E. A. Afiesimana, J. S. Pal, B. J. Abiodun, J. W. J Gutowski. , A. Adedoyin, "Simulation of West African monsoon using the RegCM3. Part I: model validation and interannual variability," *Theoretical and Applied Climatology*, 86, pp. 23-37, 2006.

[23]- K. H Cook, E. K Vizy, "Coupled model simulations of the West African monsoon system: 20th century simulations and 21st century predictions," *Journal of Climate*, 19, pp. 3681-3703, 2006.

[24]- G. Jung, "Regional Climate Change and the Impact on Hydrology in the Volta Basin of West Africa," *Thèse de l'Université de Augsburg*, Allemagne, 2006.

[25]- M. Joly, "La mousson africaine dans les scénarii du CNRM. Variabilité naturelle et changement climatique," *Rapport de fin de stage n°995*. Ecole Nationale de Météorologie (France), 2005.

[26]- K. E. Kouakou, A. M. Kouassi, F. W. Kouassi, B T. A. Goula, and Savane I., "Evaluation of the performance of a regional climate model to simulate West Africa climates: Case RegCM3 model," International Journal of Scientific & Engineering Research, 6 (3), pp. 582-590, 2015.

[27]- B. Sultan, S. Janicot, "La variabilité climatique en Afrique de l'Ouest aux échelles intrasaisonnières. 1ère partie : Analyse diagnostique de la mise en place de la mousson et de la variabilité intra-saisonnière de la convection," Sécheresse, 15 (4), pp. 321-330, 2004.

[28]- A. Alhassane, S. Salack, M. LY, I. Lona, S. Traore, B. Sarr, "Evolution des risques agro-climatiques associés aux tendances récentes du régime pluviométrique en Afrique de l'Ouest soudano-sahélienne," Sècheresse, 24, pp. 282-293, 2013.

[29]- P.M.S. Jayathilaka, P. Soni, S. Perret, H.P.W. Jayasuriya, V.M Salokhe, "Spatial assessement of climate change effects on crop suitability for major plantation crops in Sri Lanka," Regional environmental changer, pp. 55-68, 2012.

[30]- F. Bangnouls, H. Gaussen, "L'indice xérothermique," Bulletin de l'association de Géographes francais, pp. 10-16., 1952.

[31]- P. Ozenda, "Les végétaux dans la biosphère," Ed Doin, Paris, 1982.

[32]- P. Dreux, Précis d'écologie. Ed. Presse Univ. France, ' Le biologiste, Paris, 1980.

[33]- F. Bangnouls, H. Gaussen, "Les climats biologiques et leur classification," Annales de Géographie, 66° année, 335, pp. 193-220, 1957.

[34]- D.S. Wilks, “Statistical Methods in the atmospheric sciences, an introduction,” academic press, San Diego, 1995.

[35]- A. Koudou, K.A. Kouamé, K.H. Niamke, K.F. Kouamé, Saley M.B., M.G. Adja, “Contribution de l’analyse en composantes principales à la régionalisation des pluies du bassin versant du N’ZI, centre de la Cote d’Ivoire,” Revue. Ivoirienne des Sciences et. Technologie, 26, pp. 2015 156-172, 2015 :

[36]- K. Ali, S.EL. Jamali, M. Talbi, “Analyse en composantes principales : une méthode factorielle pour traiter les données didactiques,” Radisma, 2, 2007.

[37]- L. Olivier, “La spatialisation de données climatiques : une étude du climat de la Saskatchewan, Mémoire du grade maitre ès art (M.A),” université Laval, 1998.

[38]- K. E. Kouakou, “ Impacts de la variabilité climatique et du changement climatique sure les ressources en eau en Afrique de l’Ouest : Cas du bassin versant de la Comoé, Thèse de l’Université d’Abobo- Adjamé, Côte d’Ivoire,” 2011.