ISSN No:-2456-2165

Spatio-Temporal Analyses of Rainfall Extremes by Climatic Indices Method in Marahoué Region (Central West of Côte D'ivoire)

YAPI Assa Fabrice[1], OGA Yeï Marie Solange[1], KPAN Oulaï Jean Gautier[3], N'GUESSAN BI Vami Hermann[1,2], ALLECHY Fabrice Blanchard[1], et BIEMI Jean[1,2]

(1) Laboratory of Soil, Water and Geomaterials Sciences (LSWGS), University FHB, 22 BP 582 Abidjan 22 - Côte d'Ivoire.
(2) University Center for Research and Application in Remote Sensing, University FHB,22 BP 801 Abidjan 22 Côte d'Ivoire.
(3) Department of Geosciences, University Peleforo Gon Coulibaly, BP 1300 Korhogo, Côte d'Ivoire.

Abstract:- The objective in this work is to carry out a spatio-temporal study of extreme rainfall events from daily observations from the Center for Climate Prediction System Reanalysis (CFSR) by the method of climatic indices on the chronicle from 1980 to 2013 using the CLimPACT 2 master program which was used to calculate the climatic indices used in this work namely the annual total rainfall (PRCPTOT), daily rainfall intensity (SDII), annual total rainfall on very wet days (R95p), percentage of annual total rainfall on very wet days (R95pTOT), annual total rainfall on extremely wet days (R99p) and percentage of annual total rainfall on extremely wet days R99pTOT. The values of these climate indices obtained were spatialized and grouped into three 10-year periods for each climate index. Over the entire study period, the cumulative annual rainfall amounts vary from 1094.14 mm to 2012.98 mm with an average water depth ranging from 5.96 mm/d to 8.93 mm/d. Cumulative intense rainfall varies from 226.87 mm to 692.40 mm with a frequency of intense rainfall between 14.30% and 33.65%. The cumulative extreme rainfall amounts are between 67.34 mm and 295.50 mm with a frequency of extreme rainfall that varies between 4.82% and 15.09%. A gradual decline was observed in all the rainfall indicators used, reflecting the occurrence of droughts in the Marahoué region.

Keywords:- *Climate Indices, Extreme Rainfall, Marahoué, Côte d'Ivoire.*

I. INTRODUCTION

According to the United Nations Office for Disaster Risk Reduction [1], hydroclimatic hazards are the most frequent and devastating natural phenomena whose spatial amplitude has affected any country in the world during the period 1995-2015 [2]. Since the second half of the twentieth century, West Africa has been the region of the world with the largest rainfall deficit [3]. Several scientific studies carried out in West and Central Sahelian Africa have highlighted the role of rainfall in the occurrence of natural disasters such as droughts [2]. The research findings provide information on the historical evolution of rainfall conditions, namely: a gradual decline in rainfall since the 1970s, accompanied by an increase in the vulnerability of society [4]. The climatic context characterized in many West African countries (Burkina Faso, Côte d'Ivoire, Niger, Ghana, Senegal) is a decline in annual rainfall [5]. This calls for a probable drought in all these countries. This natural disaster, often caused by the scarcity of rainfall, has a very significant impact on socio-economic activities in Côte d'Ivoire and particularly those of Marahoué region whose main activity is rain-fed agriculture. The objective of this work is to carry out a spatio-temporal study of extreme rainfall events through rainfall indices in order to highlight spatio-temporal evolution of characteristics and rainfall trends that are at origin of drought sequences in study area. Specifically, a methodological approach will be adopted which consists in analyzing evolution of rainfall characteristics, namely the quantity, frequency and spatial distribution, through rainfall indices.

II. PRESENTATION OF AREA STUDY

The Marahoué region, a transition zone between forest and savannah, is located in central-western Cote d'Ivoire between longitudes 5°15' and 6°30' West and latitudes 6°00 and 8°00 North (Fig. 1). The study zone covers an area of 9,092.48 km² with Bouaflé as the regional capital. The climate is Baouléen-type and characterized by two major seasons alternating with two smaller ones: a major dry season (December to the end of February), a major rainy season (March to June), a small dry season (July to August) and a small rainy season (September to November) [6].

III. MATERIEL AND METHODS

A. Data and material

The data used in this study are daily rainfall data from seventeen weather stations covering the study area over the period 1980 to 2013 (34 years). They come from the Centre for Climate Prediction System Reanalysis (CFSR) available at: https://globalweather.tamu.edu/#pubs. The calculation of climate indices reflecting annual total rainfall, its frequencies and extremes is made available in the work of [713].

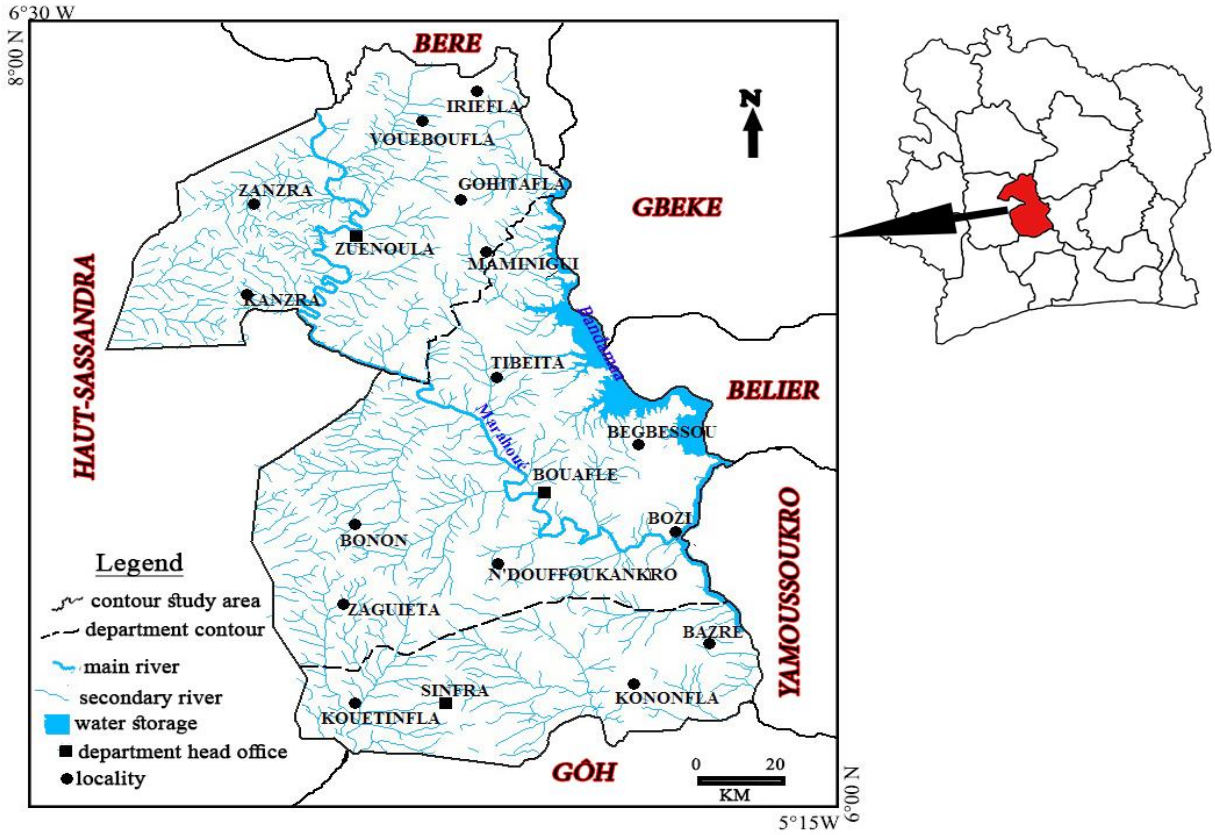

Fig. 1 : Location of Study Area

The softwares used are several types:
- XLSTAT 2016 has been used to store and statistically process rainfall data;
- Computer programs RH_test for data homogeneity testing and
- ClimPACT 2 Master for calculations of climate indices in daily time steps.

These programs are accessible from the website of Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI). ClimPACT 2 Master is a computer program dedicated to climate studies, elaborated and recommended by the WMO (World Meteorological Organization) which works under the environment of the software R ([8], [9];
- ArcGIS for establishment of thematic maps.

B. Methods

The methodology adopted in this study to analyze extreme rainfall events is the climate indices ([9], [10], [11] proposed by the Expert Team on Climate Change Detection and Indices (ETCCDI) from the ClimPACT 2 Master program. The experts of the ETCCDI have defined 27 climatic indices including 11 to characterize rainfall and 16 for extreme temperatures. These indices describe the particular characteristics of rainfall extremes, including the frequency, amplitude and persistence of rainfall events [12]. These can be grouped into four categories:
- indices based on durations ;
- indices based on intensities ;
- indices based on percentiles;
- threshold indices;

But in this study only six indices are considered, two of which are based on rainfall intensity, namely the annual total rainfall (PRCPTOT) and the daily rainfall intensity (SDII). And four indices based on the persistence of intense or extreme rainfall, these are the annual total rainfall on very wet days (R95p), the percentage of annual total rainfall on very wet days (R95pTOT), the annual total rainfall on extremely wet days (R99p) and the percentage of annual total rainfall on extremely wet days (R99pTOT).

The calculation of climate indices is a three-step process:
- quality control (QC) of the data used;
- Homogeneity test of the climatic data;
- calculation of the climatic indexes.

Before the calculation of the indices, the quality of the data is checked and the homogeneity of the data is tested.

- *Data homogeneity test*

The homogeneity of the data is verified using a computer program RHtest developed by the Meteorological Service of Canada [13] and implemented under the statistical and programming software environment R. This procedure is based on a double regression model [14].

ISSN No:-2456-2165

- *Quality control (QC) of the data used*

The quality control process helps to identify posting errors that may exist on daily data. The principles are as follows:

- missing or negative precipitation and temperature data are replaced by the value -99.9 before quality control by the software;
- it is not possible to have more than 365 to 366 daily observations per year;
- the month of February must not have more than 28 observations in any given year;

The percentage of missing data is also checked in this step as it must be less than 25%, which is a necessary condition for the computer program to calculate the indices ;

- *Calculation of climatic indices*

After quality control and testing the homogeneity of the data, the next step is to calculate the climatic indices. The validation of the values of the calculated indices follows the following criteria: the estimation error of the slope of the line resulting from the linear regression must be less than the estimated value of the slope and the P-value resulting from the associated significance test must be less than 0.05 (P-value < 0.05). Thus the trend obtained is statistically significant with a 95% confidence level [15].

The 10% and 90% percentile thresholding method was applied to highlight the cold and warm temperatures in Marahoué region.

IV. RESULTS

A. Interannual evolution of total annual rainfall and rainfall intensity in the Marahoué region from 1980 to 2013

1) Cumulative annual rainfall (PRCPTOT)

The interannual evolution of the average cumulative rainfall in the Marahoué region has been spatialized by decade in order to show which localities received the least rain during these decades (Fig. 2). The cumulative annual rainfall for the decade 1984-1993 varies between 1617.83 mm and 2012.98 mm with an average of 1764.91 mm. The least rainfall was recorded from the northeast and the central-eastern part of the study area, the localities concerned being Zuénoula, Gohitafla and Bouaflé.

Cumulative annual rainfall amounts for the decade 1994-2003 have decreased and range from 1094.14 mm to 1406 mm with an average of 1233.97 mm. The localities situated to south of Marahoué observed the highest cumulative annual rainfall of decade. However, the towns from North to Center recorded the lowest cumulative annual rainfall.

During last decade 2004-2013, the annual total rainfall intensities of rainy days have further decreased and range from 1029.28 mm to 1241 mm with an average of 1108.38 mm. The highest rainfall intensities of this period were observed in south-western part of Marahoué in localities of Kouetinfla and Sinfra. The areas located from Northeast to Center observed the lowest cumulative annual rainfall.

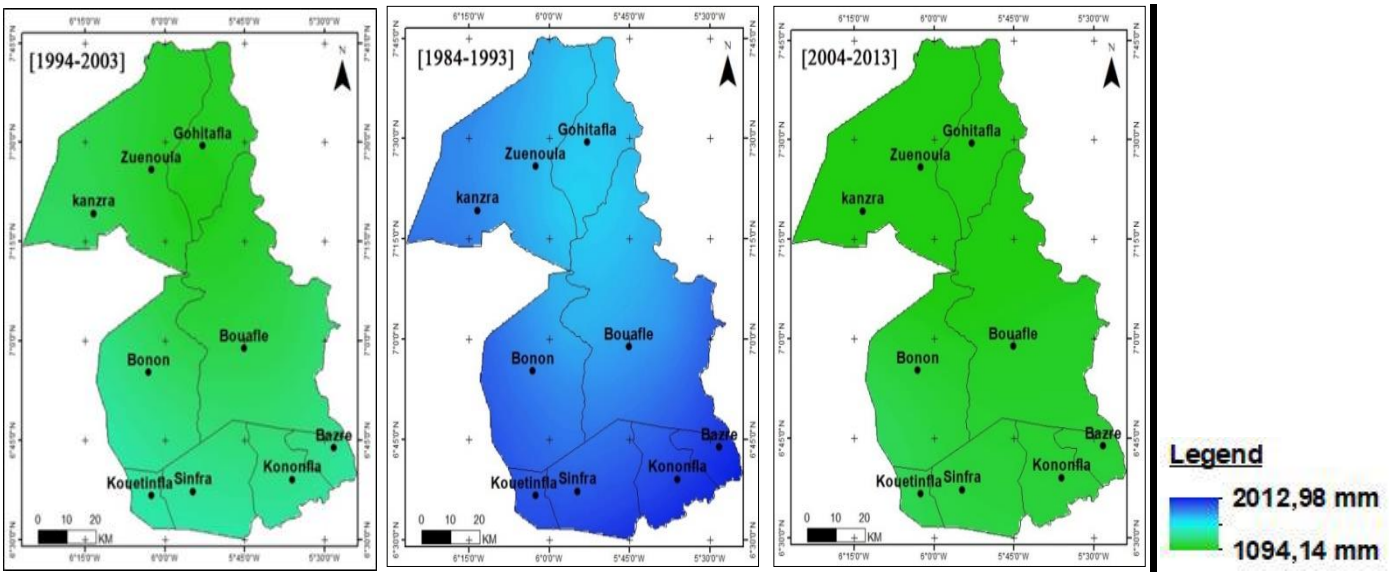

Fig. 2 : Spatialization of cumulative annual rainfall (PRCPTOT)

2) Rainfall intensity (SDII)

The spatio-temporal evolution of the precipitated water wave in the Marahoué region by decade is illustrated (Fig. 3). The average daily rainfall intensities for the decade 1984-1993 ranged from 7.84 mm/day to 8.93 mm/day with an average of 7.84 mm/day and the localities of Kouetinfla, Sinfra and Bonon were the most affected. These daily intensity values for the decade 1994-2003 range from 6.47 mm/day to 7.64 mm/day with an average of 6.99 mm/day. The localities of Zuénoula, Gohitafla and Kanzra recorded the highest values of daily rainfall intensity. During the decade 2004-2013, the daily rainfall intensities recorded ranged from 5.96 mm/day to 7.60 mm/day with an average of 6.68 mm/day and the highest daily rainfall intensities were observed in the northern localities.

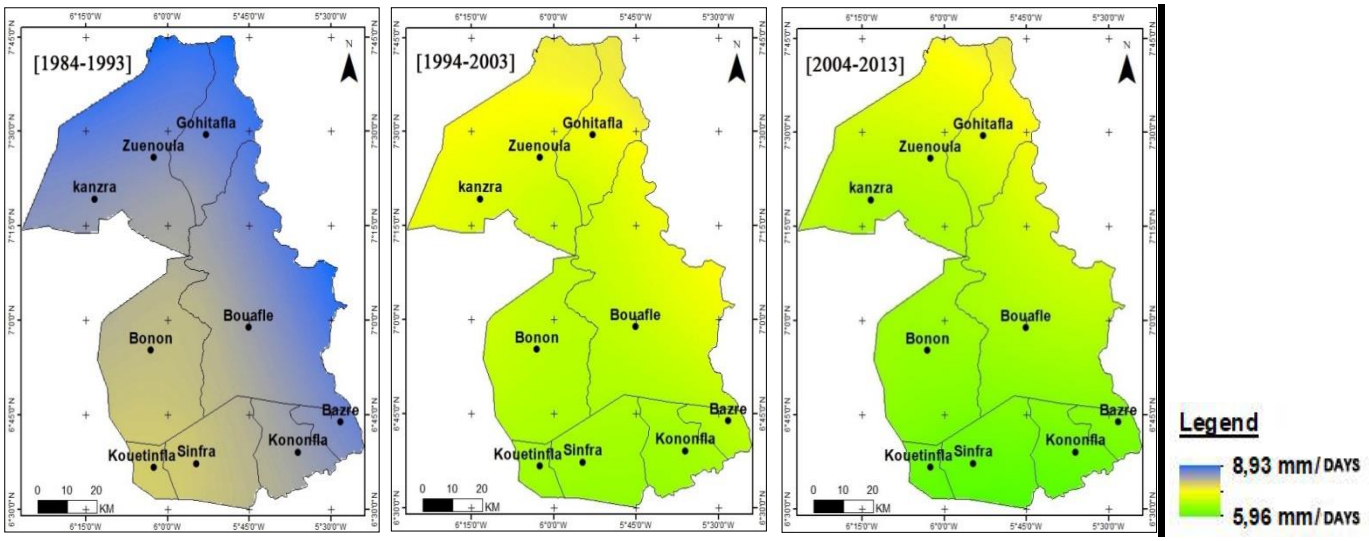

Fig. 3: Spatial evolution by decade of rainfall intensity (SDII)

B. Annual evolution of the heights and frequency of intense rainfall in the Marahoué region

1) Cumulative intense rainfall (R95P)

The spatio-temporal evolution of the cumulated intense rainfall in the study region is shown (Fig. 4). During the decade 1984-1993, the highest cumulative rainfall amounts varied between 577.60 mm and 692.40 mm with an average of 621.30 mm. The highest cumulative intense rainfall during this period was observed in the southeast of Marahoué in the localities of Kononfla and Bazré. During the period 1994 to 2003, these values observed a slight decrease and ranged from 349.53 mm to 408.20 mm with an average of 384.12 mm, a decrease of 237.18 mm. The highest cumulative heavy rains were reported in the northern and southwestern localities of the region, in the localities of Gohitafla, Zuénoula, Kanzra, Kouetinfla and Sinfra. During the period from 2004 to 2013, these high cumulative totals declined to between 226.87 mm and 300.53 mm with an average of 256.45 mm, a deficit of 127.67 mm compared to the previous decade. The lowest values were recorded in the localities of Kanzra, Sinfra, Kononfla and Bazré.

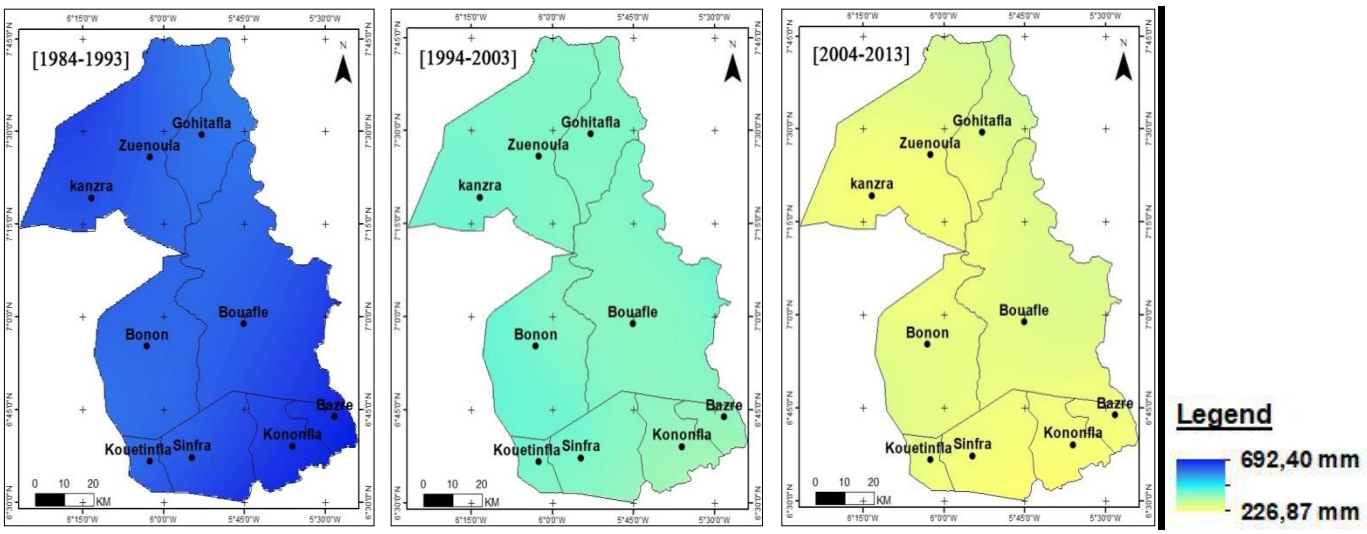

Fig.4: Spatio-temporal evolution of R95P indice

2) Frequency of intense rainfall (R95PTOT)

The spatio-temporal fluctuations in the frequency of intense rainfall in the Marahoué region are studied (Fig. 5). During the first decade 1984-1993, the frequency of intense rains ranged from 27% to 32.76% with an average of 31.72%. The highest frequencies of intense rainfall were observed in almost all of Marahoué, with the exception of the locality of Kanzra, which has low frequencies in its extreme west. During the second decade 1994-2003, the value of the frequency of intense rains was between 21.25% and 33.65% with an average of 29.67%. The lowest frequencies of intense rainfall are observed in the localities located to the south and extreme west of Kanzra. The frequencies of intense rainfall recorded during the 2004-2013 decade ranged from 14.30% to 26.40% with an average of 22.15%. It is the same localities as in the previous decade that recorded the lowest frequencies of intense rainfall.

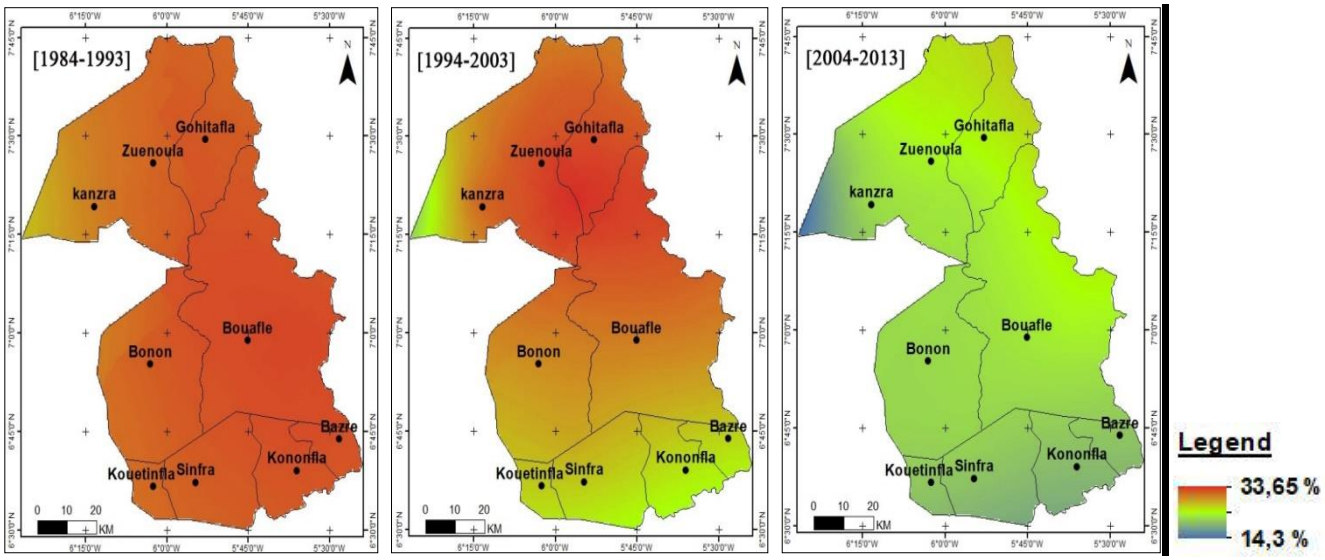

Fig. 5: Spatio-temporal evolution of the R95PTOT indice

C. Annual changes in height and frequency of extreme rainfall in region of Marahoué

1) Cumulative extreme rainfall (R99P)

The spatio-temporal evolution of the accumulation of extreme rainfall in the study area has been highlighted (Fig. 6). The cumulative extreme rainfall amounts for the decade 1984-1993 varied between 206.72 mm and 295.50 mm with an average of 249.57 mm, and the highest cumulative rainfall amounts were located in the southeast of the study area. During the 1994-2003 period, the accumulation of extreme rainfall ranged from 90.30 mm to 212.49 mm with an average of 153.83 mm, a decrease of 95.74 mm, and the highest of these values was recorded in the southwest in the localities of Kouetinfla and Sinfra. During the decade 2004-2013, the cumulative extreme rainfall fell considerably and varied between 67.34 mm and 118.50 mm with an average of 87.18 mm, i.e. a deficit of 66.65 mm, and the highest of these values was observed in the north of the study area in the localities of Gohitafla.

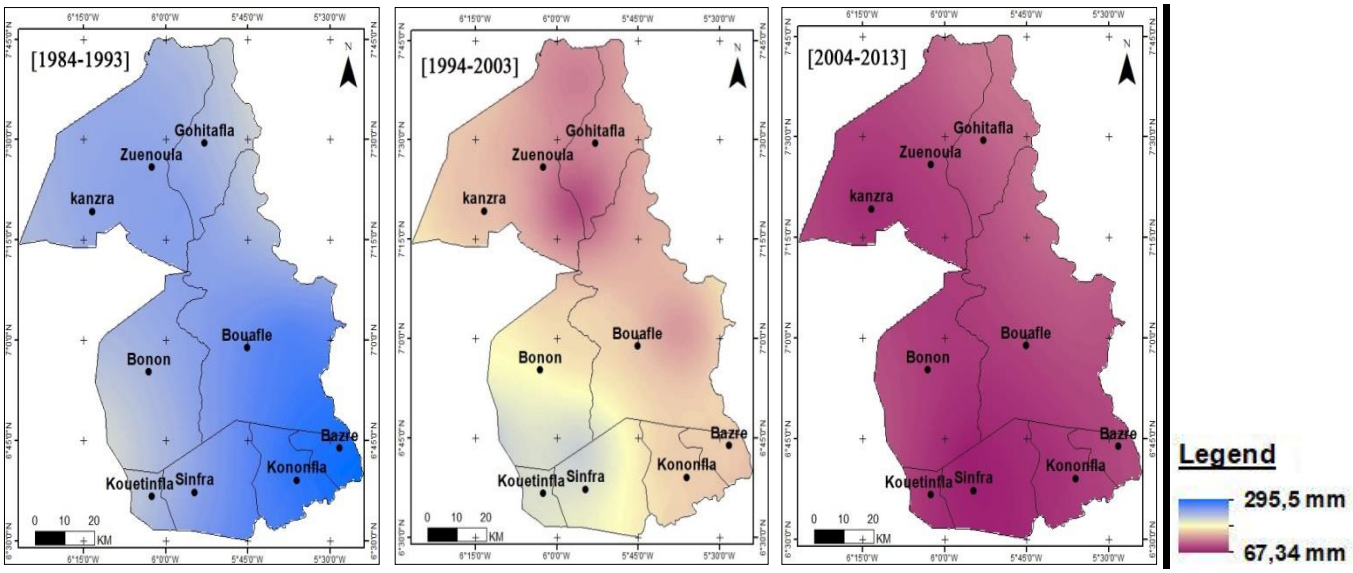

Fig. 6: Spatio-temporal evolution of the R99p indice

2) Frequency of extreme rainfall (R99PTOT)

The spatio-temporal distribution of the frequency of extreme rainfall in the Marahoué has been established (Fig. 7). During the decade 1984-1993, the frequency of extreme rainfall varied between 11% and 15.09% with an average of 13.35% and the highest frequencies were observed in the localities of Bouaflé, Kononfla and Bazré. During the second decade 1994-2003, the frequency of extreme rains ranged from 08.47% to 14.98% with an average of 11.68% and the lowest of these values were recorded in the localities of Zuénoula and Gohitafla and also in the extreme south of Kononfla and Bazré. During the period from 2004 to 2013, the frequency of extreme rainfall decreased and varied between 04.82% and 10% with an average of 07.14% or a deficit of 05.54% and the lowest frequencies were observed in the south and northwest of the study area.

ISSN No:-2456-2165

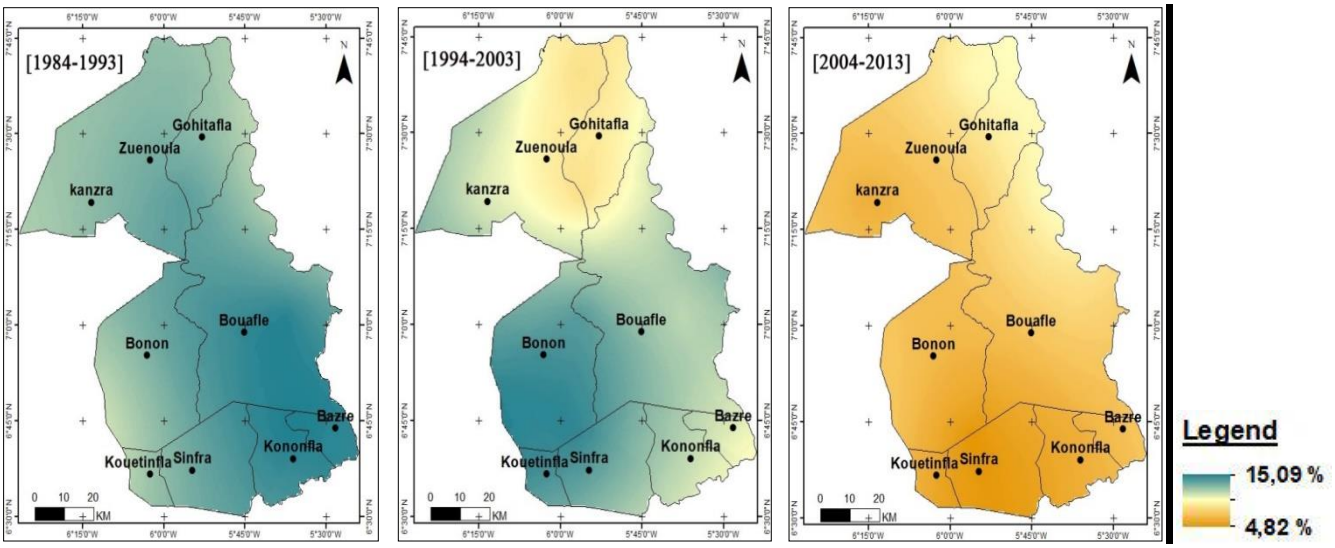

Fig. 7: Spatio-temporal evolution of the R99PTOT indice

V. DISCUSSION

A change in the daily rainfall pattern in terms of frequency and intensity has been observed in recent decades in some parts of the world and Africa. The Marahoué region shows a general decline in annual rainfall accumulation from 1980 to 2013. These results were also observed in the work of [16] and [10]. Indeed, in their work on the evolution of extreme daily weather conditions covering Southern and Western Africa, [16] showed that the regions are experiencing an overall decrease in total annual rainfall (PRCPTOT) and the number of rainy days. [10] in their analysis of rainfall in Central Africa between 1955 and 2006 came to the same conclusions. The present study shows a general decline in extreme rainfall events. The temporal evolution of daily rainfall intensity at the different measurement points shows a general downward trend that is not significant in the Marahoué region. [9] found similar results in their work in the District of Abidjan 1998 to 2015, while [17] found the same results for most of the stations in the Maghreb (Morocco, Algeria, Tunisia).

The evolution of the average precipitated water level (SDII) in Marahoué is also marked by a progressive decrease during the study period. The authors [18] also showed a progressive decrease in the precipitation per wet day in eastern Niger, but this trend is not significant. The height of rainy days (R95) and frequency of intense rainfall (R95pTOT) have a slightly increasing trend from the decade 1984-1993 to the decade 1994-2003, followed by a decreasing trend until the last decade of the 2004-2013 study period. [19] have also observed an increase in these indices in the Gôh region. [20] mentioned a downward trend in intense rainfall in the Chéliff basin in Algeria in a chronicle from 1971-2010. In the Marahoué region, our study revealed a progressive non-significant decrease in the cumulative extreme rainfall (R99p), a trend that was observed in the work of [21] in the urban area of Butembo (DRC).

VI. CONCLUSION

This study provided an overview of the spatial and temporal distribution of rainfall extremes in the Marahoué region from 1980 to 2013 using data from the Climate Prediction System Reanalysis Center (CFSR). A general downward trend in the six climate indices studied was observed in the study region. Localities located in the north and northeast of the study area are the most affected by this decline in rainfall. This could predispose these localities to progressively intense drought sequences.

REFERENCES

[1]. Centre for Research on the Epidemiology of Disasters (CRED, UNISDR). The human cost of natural disasters, a global perspective. (Centre for Research on the Epidemiology of Disaster, 58p, 2015). http://repo.floodalliance.net/jspui/44111/1165.

[2]. Bouba L., Sauvagnargues S.,Gonne B., Ayral P.A., Ombolo A., Tendances pluviométriques et aléa inondation à l'Extrême-Nord Cameroun, numéro spécial, Geo-Eco-Trop.,41(3), 2017, 339-358.

[3]. Spinoni J., Naumann G., Carrao H., Barbosa P., Vogt J., World drought frequency, duration, and severityfor 1951-2010. International Journal of Climatology, 2013, DOI: 10.1002/joc.3875.

[4]. Ozer P., Perrin D., Eau et changement climatique. Tendances et perceptions en Afrique de l'Ouest. Presses de l'Université d'Angers, 2014, 227-245, http://hdl.handle.net/2268/156390.

[5]. Hubert P., Carbonnel, J. P., Chaouche, A., Segmentation des séries hydrométéorologiques : application à des séries de précipitations et de débits de l'Afrique de l'Ouest. Journal of Hydrology, 110, 3-4, 1989, 349-367.

[6]. Irie G. R., Soro G. E., Goula B. T. A., "Changements d'états de surface et évolutions spatio-temporelles des précipitations sur le bassin versant de la Marahoué (Côte d'Ivoire)", International Journal of Innovation and Applied Studies, vol. 13, n° 2, pp.386-397, 2015.

[7]. Haylock M. R., Peterson T. C., Alves L. M., Ambrizzi T., Anunciação Y. M. T., Baez J., Barros V. R., Berlato M. A., Bidegain M., Coronel G., Corradi V., Garcia V. J., Grimm A. M., Karoly D., Marengo J. A., Marino M. B., Moncunill D. F., Nechet D., Quintana J., Rebello E., Rusticucci M., Santos J. L., Trebejo I., And Vincent L. A., "Trends in Total and Extreme South American Rainfall in 1960–2000 and Links with Sea Surface Temperature", Journal Climate, vol. 19, n° 8, pp. 1490-1512, 2006.

[8]. Alexander L., and Herold N., The indices and the ClimPACT2 software. Climate system science, 46p, 2016, https://epic.awi.de/id/eprint/49274/1/ClimPACTv2_manual.pdf.

[9]. N'guessan Bi V. H., Arona D., Adjakpa T., Kouadio B. H., Badara A. K., Kouame K., Assa Y., et Affian K., Apport de la télédétection à l'analyse spatio-temporelle de l'évolution des extrêmes pluviométriques dans le district d'Abidjan au Sud de la Cote d'ivoire. Mélange, 3, 2018, 364-378.

[10]. Aguilar A., Aziz Barry A., Brunet M., Ekang L., Fernandes A., Massoukina M., Mbah J., Mhanda A., Do Nascimento D.J., Peterson T.C., Thamba Umba, O., Tomou M., Zhang X., Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry and Zimbabwe, 1955-2006. Journal of geophysical research, 114, 2009, DO2115, doi : 10.1029/2008JDO11010.

[11]. Hountondji Y.C., De Longueville F., Ozer P., Trends in extreme rainfall events in Benin (West Africa), 1960-2000. Proceedings of the 1st International Conference of Energy, Environment and Climate Change, 26-27 August 2011, 2011.

[12]. Taïbi K., Campo García ADD., Aguado A., and Mulet Salort J. M., Early establishment response of different Pinus nigra ssp. salzmanii seed sources on contrasting environments : Implications for future reforestation programs and assisted population migration. Journal of Environmental Management, 171, 2016, 184-194.

[13]. Zhang X., Aguilar E., Sensoy S., Melkonyan H., Tagiyeva U., Ahmed N., Kutaladze N., himzadeh F., Taghipour A., Hantosh T.H., Albert P., Semawi M., Karam Ali M., Said Al-Shabibi M.-H., Al-Oulan Z., Zatari T., Khelet I.-A., Hamoud S., Sagir R., Demircan M., Eken M., Adiguzel M., lexander L., Peterson T.C., Wallis T. "Trends in Middle East climate extreme indices from 1950 to 2003". Journal of Geophysical Research 110:D22104, 2005, Available: http://DOI/10.1029/2005JD006181.

[14]. Wang G., and Schimel D., "Climate Change, Climate Modes, and Climate Impacts", Annual Review of Environment and Resources, vol. 28, pp. 1-28, 2013.

[15]. Sensoy S., Türkoğlu N., Akçakaya A., Ekici M., Demircan M., Ulupinar Y., Atay H., Tüvan A., Demirbaş H., "Trends in turkey climate indices from 1960 to 2010", 6th Atmospheric Science Symposium - ATMOS Haziran 2013, İstanbul, 2013.

[16]. New M., Hewiston B., David B., Tsiga S.A., Kruger A., Manhinsue A., Gomez B., Coelho C.A., Masisi D.N., Kalulanga E., Bulane E., Fortunata L., Mdoka M.L. Lajoie R., Evidence of trends in daily climate extremes over southern and west africa. Journal of geophysical research, 111, 2006.

[17]. Tramblay Y., El Adlouni S., Servat E Trends and variability in extreme precipitation indices over Maghreb countries. Nat. Hazards Earth Syst. Sci., 13, 2013, 3235-3248.

[18]. Ozer P., Hountondji Y.C. et Laminou Manzo O., Évolution des caractéristiques pluviométriques dans l'est du Niger de 1940 à 2007. Geo-Eco-Trop., 33, 2009, 11-30.

[19]. Balliet R., Saley B., Sorokoby M., N'Guessan BI V. H., N'dri A., Dje K.B., Biemi J., Evolution des extremes pluviometrique dans la region du Gôh (Centre Ouest de la Côte d'Ivoire). European scientific journal, 12, 2016, 14.

[20]. Taibi, S., Meddi, M., Mahé, G., Assani, A., Relationships between atmospheric circulation indices and rainfall in Northern Algeria and comparison of observed and RCM-generated rainfall. Theoretical and applied climatology, 2015, 1-17.

[21]. Sahani M., Moeyersons J., Vandecasteele I., Trefois P., Ozer P.,: Évolution des caractéristiques pluviométriques dans la zone urbaine de butembo (RDC) de 1957 à 2010. Geo-Eco-Trop., (36), 2012, 121-136.