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Study of the Spatial and Temporal Dynamics of Rainfall over the Period 1991-2020 in Burkina Faso

Yélézouomin Stéphane Corentin Some[a]*, Alimata Zorom[b], Wièmè Some[c]

[a,c]Laboratoire de Recherche en Sciences Humaines et Sociales (LABOSHS), Université Norbert ZONGO, Koudougou, Burkina Faso
[b]Faculty of Human Sciences, Department of Geography, Norbert Zongo University, Koudougou, Burkina Faso
[c]Permanent Secretariat in charge of crisis management and vulnerability in livestock
[a]Email: corentin.some@gmail.com
[b]Email: alimatazorom@gmail.com
[c]Email: wiemesome@gmail.com

Abstract

The spatial and temporal variability of rainfall is a major constraint for the development of socio-economic activities in Burkina Faso. The objective of this work is to study the spatial and temporal dynamics of rainfall across the country in order to guide policy measures for major disaster management. The methodology is based on the mapping of statistical metrics calculated on time series of annual cumulated rainfall from CHIRPS data and the annual number of rainy days estimated by the ANAM over the period 1991-2020. The results indicate an average variability in rainfall over the 1991-2020 normal. The persistence of drought in the Far West is accompanied by a loss of rainfall. The approach based on the two data sources presents similar information for the assessment of rainfall variability, complementary for the estimated rainfall trend areas, and the frequency of drought and contradictory for assessing the frequency of wet years.

Keywords: Burkina Faso; rainfall dynamic; spatial and temporal analysis.

1. Introduction

For several years, West Africa has been experiencing intense climate change. In this part of Africa, changes in rainfall have been observed since the early 1970s. Studies conducted in Senegal, Guinea-Bissau, Guinea-Conakry, Mali and Burkina Faso since 1966 have shown changes in rainfall ([1,2]. More than 80% of the Sahel countries depend on agriculture and livestock as their main economic activity. In Burkina Faso, these activities depend on the climate, especially seasonal rainfall and its variations.

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* Corresponding author.

The rainfall variable is one of the most variable climate variables in the world. In Burkina Faso, rainfall ranges from 400 to 1200 mm [3]. These extremes indicate changes in rainfall. Given the development problems that may arise in the country's economic sector, a good understanding of the variability of rainfall is necessary for satisfactory planning and development. This article aims to analyze the spatial and temporal dynamics of rainfall on the new normal 1991 to 2020 in Burkina Faso. More specifically, the behaviour of drought and wetlands should be described using a time series of cumulative rainfall and a statistical measure of the number of rainy days per year.

2. Materials and methods

2.1 Study area

Burkina Faso is a country located in the heart of West Africa between 5°30' west and 2°40' east longitude and between 9°30' and 15°15' north latitude. It is limited to the north and north-west by Mali, to the east by Niger, to the south-east by Benin, to the south by Togo, Ghana, and to the south-west by Côte d'Ivoire (Figure 1: Study area location). Its area is 274,200 km ² with a population of 20,487,979 inhabitants according to the 2019 RGPH. This area of West Africa is under the influence of a tropical climate with alternating seasons (dry and winter season); with a longer winter season than the dry season. Annual rainfall ranges from 400 mm to 1200 mm [3].

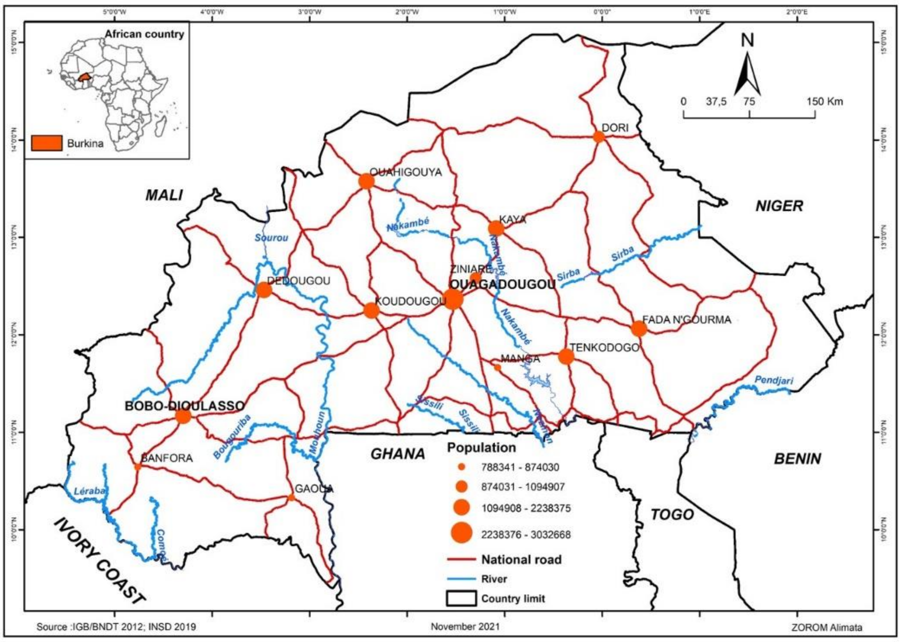

Figure 1: Study area location

2.2 Material

The hardware for this study consists of rainfall data and software. The data used are monthly satellite-estimated rainfall data from 1991 to 2020 for Africa (40 N - 40 S, 20 W- 55 E) with a spatial resolution of 0.05°*0.05°. This data comes from the monthly CHIRPS (Climate Hazards Group Infrared Rainfall With Stations) database provided by USGS (United States Geological Survey) to FEWSNET (Famine Early Warning Systems Network). Satellite rainfall data are essentially annual rainfall. CHIRPS rainfall data are collected from satellite images. CHIRPS is an estimate of rainfall from rainfall and satellite observation. They can be downloaded from htp://htp.chc.ucsb.edu/pub/org/chc/products/CHIRPS-2.0. The estimated rainfall data also refer to the annual number of rainy days, obtained from the National Meteorology Agency in Burkina Faso (ANAM). The tools used for data analysis are GeoCLIM , ArcGIS , and Microsoft Excel's office package . The GeoCLIM software was used to extract the monthly rainfall totals. ArcGIS was used for spatial analysis and mapping. Microsoft's office package was used for time series analysis.

2.3 Methods

The methodology is based on the spatial and temporal analysis of rainfall observed over the period 1991-2020 by commune. The whole territory was covered with 351 points corresponding to the centroids of the communes. The temporal analysis concerned the calculation of the temporal statistical indicators on the 351 data acquisition points. These temporal statistical indicators are: the coefficient of variation (CV), the slope of the trend line and the standardised index of cumulated rainfall (SPI). For the analysis of rainfall variation, the Pearson coefficient of variation was calculated. For trend analysis, the slope was calculated by adjusting the cumulated rainfall curve and the annual number of rainy days by the least squares method of the regression line slope written as follows:[a] . $Y = ax + b$/(xi-xm) $a = \boldsymbol{\Sigma}(\boldsymbol{xi} - \boldsymbol{xm})(\boldsymbol{yi} - \boldsymbol{ym})2$ and/or = (ym-axm). To determine the wet and dry character of a one-year locality, the SPI was calculated[b]

Table 1: WMO Proposed 7-Class PPS Classification, 2012.

Value of SPI	Dryness severity class
>+2.0	Extremely wet
+1.5 à+ 1.99	Very wet
+1.0 à+ 1.49	Moderately humid
-0.99 à +0.99	Near normal
-1.0 à -1.49	Moderately dry
-1.5 à-1.99	Severely dry
< -2.0	Extremely dry

The spatial part concerned the spatial interpolation of the temporal indices. Coefficients of variation, slope of

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[a] $CV = \frac{\sigma}{\mu} * 100$. CV: Coefficient of Variation; σ: Standard deviation of cumulated rainfall and the number of days of rain over the study period and μ: the average of cumulated rainfall and the number of days of rain.

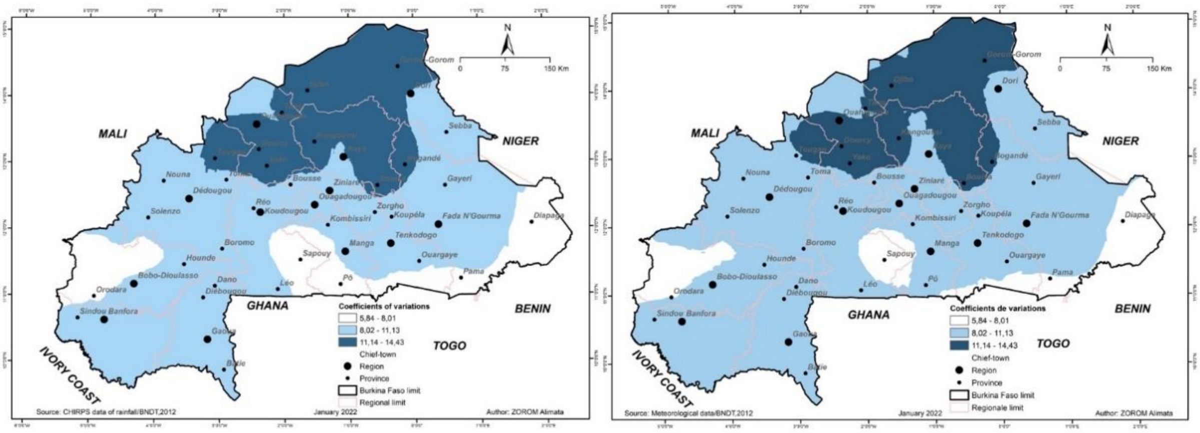
[b] SPI=(Xi-Xm)/σ where Xi: Year's Rainfall Height i (mm), Xm: Mean Rainfall Height over the Study Period (mm), σ: Standard Deviation of Cumulated Rainfall and Number of Rainy Days over the Study Period.

trend lines and SPI were interpolated and spatialized. The interpolation method used is regular kriging. The classification of the different statistical metrics of the annual rainfall totals and the annual number of rainy days is done by the Jenks natural threshold method based on the break analysis of the data series.

3. Results

3.1 Spatial variation of rainfall over normal 1991-2020

Figure 2 shows the different areas of rainfall variability captured by two statistical metrics based on the 1991-2020 normal. These are the coefficients of variation of rainfall culmuls (Figure 1.a) and the coefficient of variation of the annual number of estimated raindays during the year (Figure 1.b). The rainfall variation classes (low, medium and high) were obtained by the natural cut-off method based on the time series break analysis. A strong spatial simularity of the classes given in Figure 1.a and Figure 1.b. In other words, the different classes of rainfall variability were captured in virtually the same way using these two types of statistical metrics from different sources. In general, the variability of rainfall over the normal 1991-2020 is considered average (CV between 8 and 10%) for Burkina. Areas of high rainfall variation (CV between 11 and 13%) are observed in the northern part of the country, especially in the Sahel, Central-North and Northern regions. Areas of low rainfall variability (CV between 5 and 7%) are observed mainly in the border municipalities of Togo, Benin and Mali, including the municipality of Orodara in the west. These variabilities are related to the penetration quality of the monsoon at the beginning of the rainy season. The variability of rainfall in Burkina Faso is not as contrasted on the normal 1991-2020. But it follows a gradient of latitude, the highest values of which are observed in the North and the lowest in the South.



a- Variation of cumulated rainfall

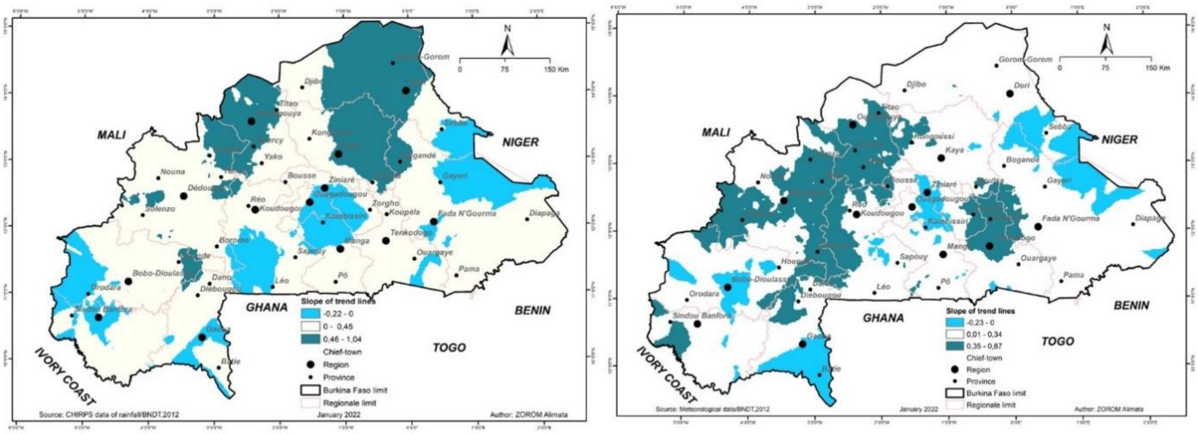
b- Variation in annual number of rainy days

Figure 2: Variation of rainfall in Burkina Faso over normal 1991-2020

3.2 Rainfall trends over normal 1991-2020

Figure 3 shows the rainfall trend estimated on the 1991-2020 normal using both time series. This is the YTD rainfall and the number of rainy days in the year. Figure 3.a and Figure 3.b provide a spatial representation of slope values from the trend lines of the two time series. Rainfall trend areas are derived from the natural cut-off method. These are: i) areas of rainfall gain (slope between 0.46 and 1.04), areas of rainfall loss (slope between -

0.22 and 0) and areas that have not experienced a major change (slope between 0 and 0.45). Unlike the rainfall variability observed in Figure 1, the two metrics used do not capture areas of estimated rainfall trends in the same way. The information provided by these two metrics can be complementary. There are also identical or overlapping catch areas and single catch areas that are specific to each statistical metric. Based on these two metrics, much of the national territory does not record a change in rainfall trend. Rainfall losses are isolated in the Sudanese climate zone and follow an oblique monsoon penetration gradient. Large areas of rainfall gain are recorded in the Sahelian climate zone with the analysis of the CHIRPS (Cumulated rainfall) data, while these are most observed in the North Sudanese climate zone with the ANAM data (number of rainy days in the year). The high variability in rainfall observed in the northern part (Figure 1.a) is accompanied by areas of rainfall gains (Figure 3.a). Analysis of the rainfall trend areas captured by these two metrics (Figure 2) reveals that the zones of change in rainfall are observed in Burkina on the normal 1991-2020. The contrasts observed in the change in rainfall areas could be explained either by the persistence of drought zones or wetlands in some parts of the country.



a- Trend of cumulated rainfall

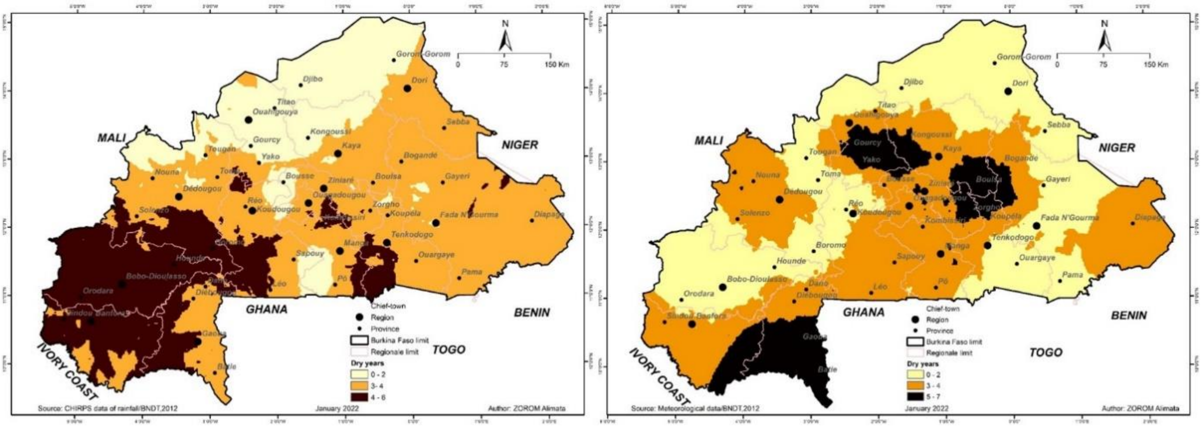
b- Trend in annual number of rainy days

Figure 3: Rainfall trends in Burkina Faso over normal 1991-2020

3.3 Dry Year Frequencies over Normal 1991 – 2020

Figure 4 shows the drought persistence space using both time series. These are the year-to-date rainfall from the CHIRPS data and the number of rainy days of the year provided by the ANAM. Drought persistence is assessed by the number of dry years over normal 1991-2020. The classes of years of onset of drought are appreciated from low for a frequency of 0 to 2 years, from average for 3 to 4 years and strong for a frequency of occurrence of 4 to 6 years. Figures 4.a and 4.b indicate that the two metrics (cumulation of pericipations and number of rainy days in the year) also do not capture the persistence spaces of the drought hazard in the same way. CHIPRS data indicate that drought is more persistent in the western part compared to the eastern part covering the fragile Sahel area of Burkina Faso. This is consistent with the rainfall trend observed in the far west (Figure 3.a). This part is indeed marked by areas of rain loss. However, the results of the analysis from the ANAM data with the number of rainy days in the year reveal the existence of two poles of drought persistence in Burkina on the normal 1991-2020. The locations are in the extreme south-west and central parts of the country (Figure 4.b).

The persistence of drought in the central part of the country seems to be superimposed with the areas of rainfall gain observed in Figure 3.b using the same time series of ANAM data. This could be due to data interpolation bias.



a- Number of dry years of cumulated rainfall

b- Number of dry years of annual number of rain days

Figure 4: frequency Dry years in Burkina Faso on normal 1991-2020

3.4 Frequency of wet years on normal 1991-2020

Figure 5 shows the occupancy space of wet years using both time series. These are the year-to-date rainfall from the CHIRPS data and the number of rainy days of the year provided by the ANAM. Three assessment classes were provided by the natural threshold method. These wet-year frequency classes (low, medium and high) are presented in Figure 5.a for cumulative rainfall and Figure 5.b for the number of rainy days in the year. The occupancy space of wet years varies greatly depending on the data source used. For both data sources, Burkina Faso is characterized by an average frequency of wet years over normal 1991 to 2020. However, areas of high frequency of wet years are confirmed by both data sources. However, areas of contradictions concerning the presence of very humid areas and low wetlands are observed by comparing the CHIRPS and ANAM data. This could perhaps be explained by the underestimation and overestimation of rainfall using CHIRPS data or by the inadequacy of measurement stations to capture the spatial contrast of rainfall.

In short, the two data sources present almost similar information for the assessment of the variability of rainfall, complementary to the analysis of the areas of rainfall trend estimated, and contradictory for the assessment of the frequency of the wetter years. However, for the assessment of drought persistence the CHIPRS data indicated good consistency with the areas of estimated rainfall gain or loss.

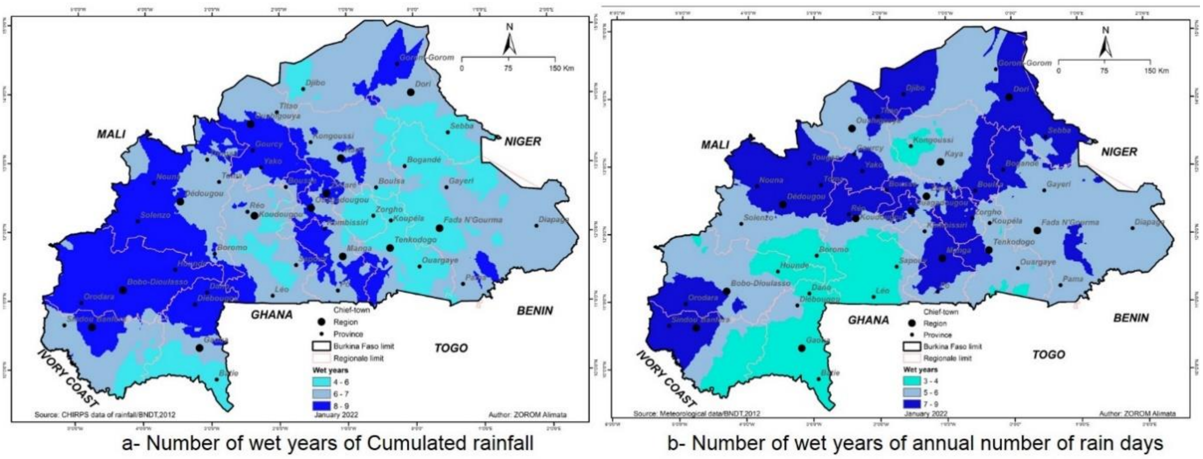


Figure 5: frequency of Wet years in Burkina Faso on normal 1991-2020

4. Discussion

The objective of this study is to analyze the spatial and temporal dynamics of rainfall in Burkina Faso in order to help with good decision-making in the various sectors of economic activity of the country. Two lines of evidence were used to strengthen analyses of rainfall behaviour over normal 1991-2020. These are the monthly rainfall totals estimated by the CHIRPS method and the annual number of rainy days provided by the ANAM. What are the lessons learned from this approach? are they consistent with the different sources of information available in the literature?

The most interesting information for the governance of rainfall risks related to economic activities are drought and floods [4,5]. However, this approach does not identify flood phenomena because hazard mapping has not been associated with vulnerability mapping [6]. Our ideas for discussion will be refocused on the behaviour of the drought hazard over the period of 1991-2020 (new normal) compared to that of 1981-2010 (old normal) in order to assess the situation of the current rainfall context in Burkina Faso. The long-standing debate between authors in the literature has focused on the end or continuation of drought in the Sahel [7,8] . What follow-up can we give to this hypothesis based on our observed results on Burkina Faso? Are the statistical metrics used relevant? In the literature, it is reported that rainfall metrics can be considered as variables of interest for climate study and monitoring of the agropastoral campaign [9,10,11]. In addition, some authors have reported that the thermal time of the rainy season, the frequency and distribution of pockets of drought are more determining factors for crop production [9,12]. The statistical metrics used in this study were: the coefficient of variation (CV), the slope of the trend line, the frequencies of dry and wet years. These metrics were calculated on annual time series of rainfall and numbers of rainy days. To this end we are in a debate about drought as a weather phenomenon. Our results provided by these two data sources are part of a logical approach of complementarity of information on drought. This is tantamount to questioning the evolution of these statistical metrics over the period 1991-2020 compared to those of 1981-2010. So, has the variability of rainfall decreased? Are there more areas of rainfall gains or losses? Has the frequency of dry years decreased? By examining these issues, we can better appreciate Burkina Faso’s current rainfall context in relation to its past. The ideal of this study was to make the same analyses on the 1981-2010 normal in order to facilitate the comparison of period. However, the

1981-2010 normal covers a period of severe drought and the available information can allow reliable comparisons with the results obtained.

For the variability of rainfall, our class values of the coefficients of variation found are slightly below the values reported in the different climatic zones of Burkina over the period 1993 to 2017 by **[13].** The CV values reported using weather station data range from 4.1% to 10% for South Sudan, 9.7% to 18.6% for North Sudan, and 14.4% to 22.2% for the Sahelian climate [13]. Rainfall and the Coefficient of Variation are two inversely related parameters [14]. Indeed, the Coefficient of Variation tends to be higher, in zones with drier climates [14,15]. The Coefficient of Variation can be as high as 37% for a combined annual rainfall of 200 to 300 mm, 21% for 700 to 800 mm and 17% for 1000 to 2000 mm [15]. Drought is the most explanatory factor for the increase in VC in the Sahel region. Periods of severe drought (1968 to 1995) were characterized by very high values of the coefficient of variation of rainfall [16]. Many authors have reported that pockets of short-lived droughts are now more frequent and numerous, as well as for wet pockets during the season [17]. The variability of rainfall in the Sahel is largely explained by that of multidecadal variability in the Atlantic [9,18,19]. There is a reverse connection between the surface temperature of the North Atlantic Ocean (TNA) and the drought period [16]. Indeed, when the surface temperature of the Atlantic Ocean increases, the indices associated with dry years are reduced in favour of rainy years [16].

The decrease in rainfall variability observed is thought to be due to a rainfall recovery phase (1991-2020). The rainfall cover corresponds to an improvement in rainfall after the period of great drought. Gains in cumulated rainfall are also explained by the period of recovery in rainfall just after the severe drought of 1983-87[7]. The 1981-2010 normal covers the rainfall recovery phase. As a result, it can record more areas of rainfall gain than the normal 1991-2020. In addition, our results showed that the zones of change of rainfall in Burkina Faso are observed on the normal 1991-2020. Drought is more persistent in the western part compared to the eastern part covering the fragile Sahel area. Our results corroborate with [9] results on the analysis of climate variability and change in the Sahel. Burkina Faso is located in the Sahel rainfall transition zone. A zonal analysis using the Standardised Rainfall Index (SPI) distinguishing the eastern part (Chad and eastern Niger) from the western part of the Sahel (Senegal and western Mali) revealed the existence of a clear climate divide between these two regions [20]. Drought continues in the western part of the Sahel while the eastern part is experiencing a return to wetter conditions [9]. This was explained by the fact that the warm hearth of the Indian Ocean moved west[9].

5. Conclusion

In short, we can remember that the mapping of statistical metrics has made it possible to make a situation of the state of drought on the new normal 1991-2020 in Burkina Faso. The statistical metrics were calculated using time series of year-to-date rainfall from CHIRPS data and the annual number of rain days estimated by the ANAM. These statistical metrics were the coefficient of variation, the slope of the regression line, the frequency of drought. The results indicate a wetter normal with a decrease in rainfall variability compared to the 1981-2010 normal. The persistence of drought in the Far West is accompanied by a loss of rainfall. The approach based on the two data sources presents similar information for the assessment of rainfall variability, complementary for the estimated rainfall trend areas, and the frequency of drought and contradictory for assessing the frequency of wet years. The results on the state of drought corroborate the information from the existing literature on the Sahel.

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