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Relationships Between Rainfall And Vegetation Production During The Period 1999-2019 In Burkina Faso

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Abstract – Burkina Faso is a country of transition between the Saharan desert and rainforests. Over six hundred kilometres from the north-east to the south-west, there is a strong variation in rainfall with four plant areas and strong heterogeneities in human densities and activities. Since vegetation is largely dependent on precipitation, the objective of this study is to study the relationships between precipitation and vegetation in Burkina Faso. The methodology is based on spatio-temporal analysis of correlations between FAPAR (a vegetation index) and rainfall parameters (cumulated rainfall, annual number of rainy days). This study showed a strong and significant correlation between precipitation metrics and vegetation. It also revealed facial variations across the country. The correlations are more pronounced in regions with high population densities and natural formations consisting of steppe and savannah with a strong dominance of rainfed crops and annual herbaceous plants. Low correlations are observed in areas of high conservation areas and classified forests with higher abundance of woody and other multi-year species

Keywords – Burkina Faso, rainfall, vegetation, FAPAR

I. INTRODUCTION

Precipitation plays a key role in economic activity, the water cycle, plant development, and ecosystem functioning. Sahelian vegetation is particularly affected by rainfall variability [1], [2]. In arid areas, annual vegetation production is dependent on variations in water resources [3], [4]. In semi-arid areas, vegetation is affected by the number of rainy days and the period of the rainy season [5] Burkina Faso is a country of transition between the Saharan desert regions and the forested regions of the Gulf of Guinea. It is marked by climatic instability and this is reflected by spatial and temporal variability in climatic parameters, particularly precipitation [6]. At the vegetative level, rainfall is the main source of water for plants [7]. Changes in the precipitation regime could then have an impact on their development. Many authors have studied the relationships between vegetation evolution and rainfall using vegetation indices in Sahelian Africa [8], [9, [10], [11], [12], [13], [14], [15], [16]. These previous studies have used the NDVI (Normalized Difference Vegetation Index). An index whose saturation in the forest can induce biases in the appreciation of this relation vegetation-precipitation. In Burkina Faso few studies have addressed this issue. The objective of the work is to study the relationship between the spatial and temporal dynamics of precipitation parameters (annual cumulation and annual number of rainy days) and that of vegetation using the FAPAR product between 1999 and 2019 in Burkina Faso.

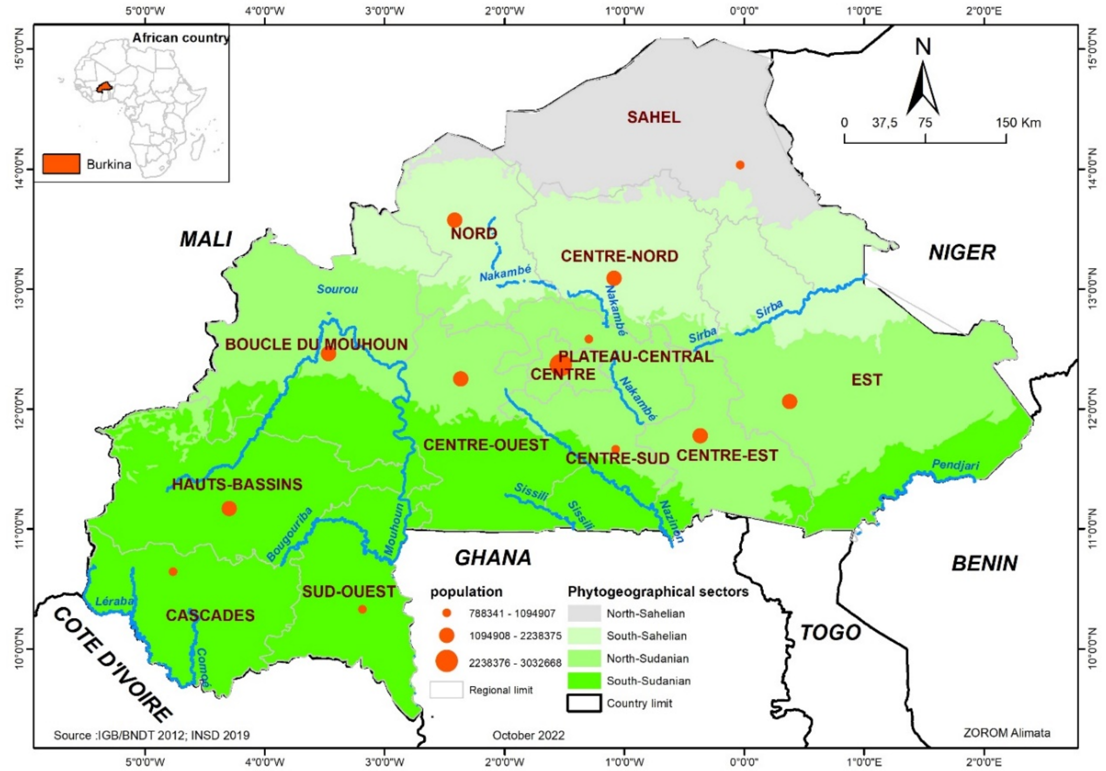
II. MATERIALS AND METHODS

2.1. Study area

Burkina Faso is located in 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 (Map 1). This country is in transition between the Sahara desert and the equatorial climate of the Gulf of Guinea. It has a tropical climate with contrasting season with a wet season starting between May and June and ending between September and October. Rainfall ranges from 1200 mm in the southwest of the country to 450 mm in the northeast [17]. Monthly mean temperatures are still above 20°, with maxima ranging from 30-34°C in April to 23-25°C between December and January.

In terms of vegetation, Burkina Faso is in the Sudanian and Sahelian phytogeographic domain. There are four plant-based sectors: North Sahelian, South Sahelian, North Sudanian and South Sudanian [18].

On a human level, the country has a high diversity in terms of density, with high densities in the central and Hauts-Bassins regions and very low borders on the east, north and south-west.



Map1: Situation of Burkina Faso

2.2. Material

Hardware consists of data and software. The data used relate to precipitation data, vegetation data and related site data. Rainfall data are mainly cumulated rainfall and the annual number of rainy days. The annual precipitation totals used are satellite data of monthly series from 1991 to 2020 on Africa (40 N - 40 S, 20 W- 55 E) with a spatial resolution of 0.05°. This data comes from the monthly CHIRPS (Climate Hazards Group Infrared Precipitation With Stations) database provided by USGS (United States Geological Survey) to FEWSNET (Famine Early Warning Systems Network)1. Data on the annual number of rainy days come from the National Meteorological Agency (ANAM) of Burkina Faso. These are CHIRPS satellite data corrected at the station and cover the period 1991 to 2020. The annual number of rainy days is the total number of days that have more than 1 mm of precipitation between the beginning and end of the rainy season.

Vegetation data are from the Chlorophyll Activity Estimation Satellite System. They correspond to the 1999-2019 time series of[2] satellite images FAPAR (Fraction of Absorbed Photosynthetically Active Radiation) The limitation to 1999 corresponds in fact to the beginning of the production of this vegetation index resulting from the improvement of CYCLOPES and MODIS and come from the SPOT sensors -VEGETATION and PROBA-V. The metrics used for this study are the maximums and averages of the last decades from August to the second decade of October corresponding to the period of the vegetative maximum.

To these two main data is added the topographic data bank (BNDT) which contains geographical data relating to Burkina Faso and covering many topics such as hydrography, protected areas, the boundaries of phytogeographical areas and the different levels of administrative subdivision of the territory.

1 http://htp.chc.ucsb.edu/pub/org/chc/products/CHIRPS-2.0

2 http://land.copernicus.eu/

For data processing, ArcGIS, GeoCLIM, SPIRIT, the Microsoft Office Excel Package and XLSAT were used: SPIRIT to extract the vegetation parameters (maximum and average), GeoCLIM3 to extract digital counts from rainfall cumulation images, ArcGIS for spatial analysis and cartographic writing, Microsoft Office Excel and XLSAT for statistical work.

2.3. Methods

The methodology is based on spatial and temporal analysis of precipitation and vegetation parameters. Temporal statistical analysis focused on the calculation of the correlation coefficient. The correlation coefficient used in this study is that of Bravais-Person (Rp). It is a normalization of the covariance by the product of the standard deviations of the variables. Its calculation is based on the following formula: Rp= (σXY/σXσY), where σXY is the covariance of the variables x and y and σXσY is the product of their standard deviations. Bravais-Person correlation coefficients were calculated between:

- Annual rainfall totals and FAPARmax,
- Annual rainfall totals and average FAPARs,
- Annual numbers of rainy days and FAPARmax,
- Annual numbers of rainy days and average FAPARs.

For spatial analysis, the correlation coefficients were spatialized and interpolated using ordinary Krigeage.

III. Results

Figure 1 shows the spatialization and interpolation of correlations between vegetation and precipitation metrics over the period 1999-2019. Figure1a shows that there is an overall correlation between rainfall cumulation and FAPARmax. However, there are large regional disparities. Strong correlations are observed in the Sahelian domain and north sector of the Sudanian domain. On the other hand, the South-East and South-West parts of the South sector of the Sudanian domain have weak correlations.

In terms of the correlation between the annual number of rainy days and the FAPARmax, we note that the weak correlations (correlation coefficient between -0.61 and 0.10%) are more observed in the Sudanian domain, Overall, however, correlations are weak across the country with the exception of some regions such as the north, a part of the south-west and the central plateau which have islands of strong correlations (correlation coefficient between 0.33 and 0.73%) (Figure 1 b).

Figure 1c shows that there is a strong correlation between rainfall totals and the FAPARmean. This correlation ranges from -0.38 to 0.89%. The importance of the correlation varies according to phytogeographic domains. The strongest correlations are observed in the Sahelian domain (correlation coefficient between 0.58 and 0.88) and a large part of the North-Sudanian sector. The low correlations (correlation coefficient between - 0.38 and 0.37%) are observed in the South-Sudanian sector.

The results of the correlation between the FAPARmean and the annual number of rainy days are similar to that of the cumulated rainfall and the FAPARmean (Figure 1 d). The results show a significant correlation between the mean FAPARand the annual number of rainy days. Overall, the correlations are positive and strong over the whole territory outside of a few areas that have negative correlations. At this level too, the Sahelian domain and the north sector of the Sudanian domain show strong correlations.

3 https://wiki.chc.ucsb.edu/GeoCLIM

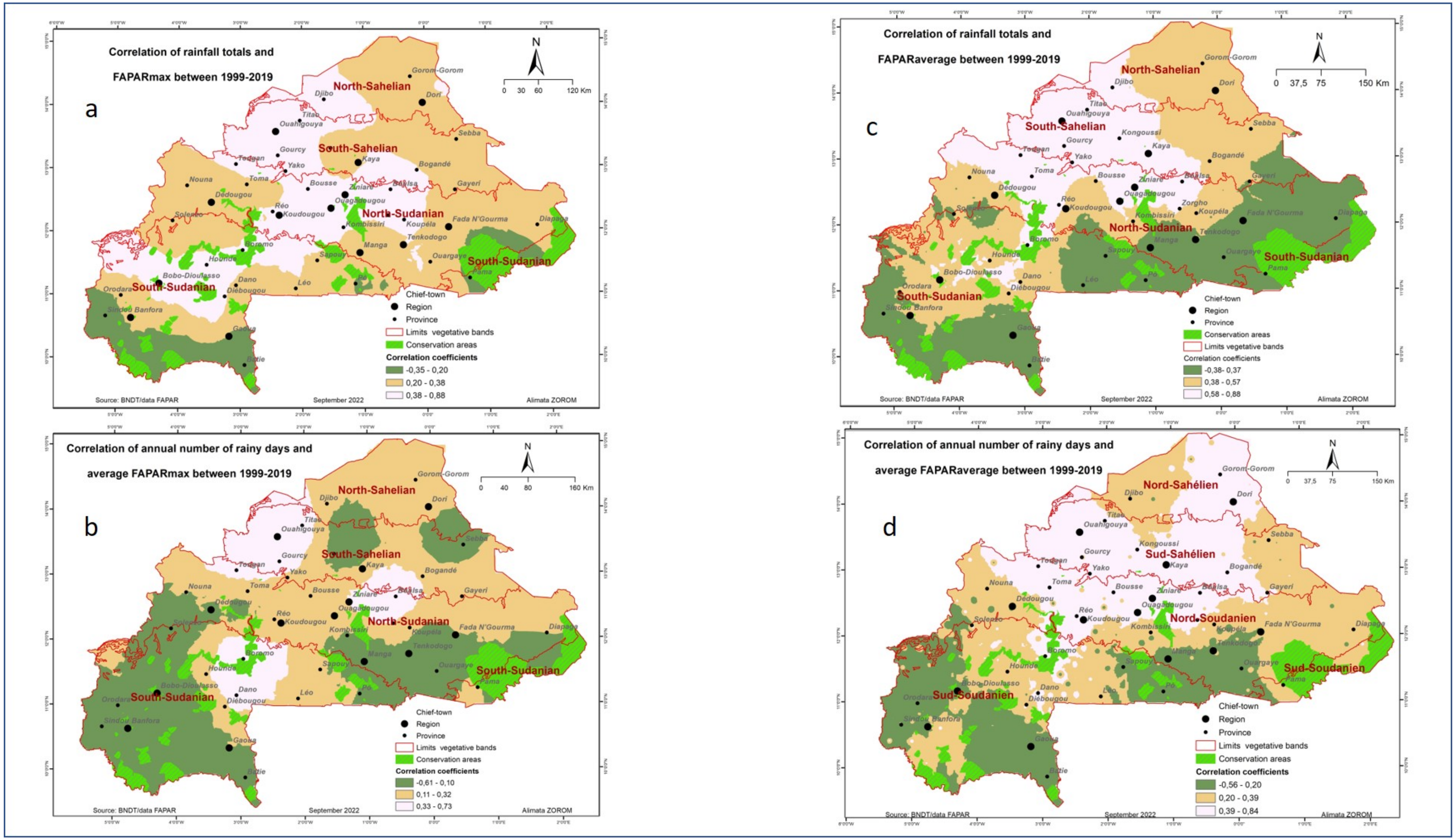


Figure 1: Correlations between precipitation and vegetation metrics

Better interpretation of the results of the correlation coefficients is possible thanks to tests analyses of significant named p-value. The p-value is a statistical measure between 0 and 1. When p below 0.05 it means that the values are statistically significant meaning the probability that a value is due to chance does not exceed 5% and the confidence threshold is 95%. If the p is greater than 0.05%, this means that the values are statistically insignificant and the probability that the values are due to chance is high. Our significance tests calculated with maxima, mean vegetation and precipitation metrics give the results assigned in Figure 2.

Overall, the tests carried out between the rainfall totals and the FAPARmax show that the correlations are significant in the different vegetation zones especially in the Sahelian domain **(Figure 2a)**. On the other hand, the south-Sudanian sector, especially in the extreme southwest, south and east, has statistically insignificant values.

Based on the results obtained from the correlations between the FAPARmax and the annual number of rainy days, it appears that the significant is not perfect enough. This shows that there is no strong link between the FAPARmax and the annual number of rainy days **(Figure 2 b).**

Figure 2c shows that the correlation tests performed on rainfall cumulations and the mean FAPARyield a 95% confidence threshold. The entire Sahelian domain, a large part of the North-Sudanian domain at the centre and north-west level and also a part of the South-Sudanian domain, a little in the in the Cascades and the Hauts-basins show statistically significant values. Non-significant values are observed in the North-Sudanian sector to the east and to the south - west in the South Sudanese sector. Non-significant values are observed more in the South-Sudanian sector and part of the North sector of the Sudanian domain in the extreme east.

Unlike the tests performed between the FAPARmax and the annual number of rainy days, the significance tests performed between the annual number of rainy days and the FAPARmean are well marked. The significant threshold also reached 95%. The Sahelian domain and the North sector of the Sudanian domain have statistically significant values, while the South Sudanian sector has non-significant values (**Figure 2 d**).

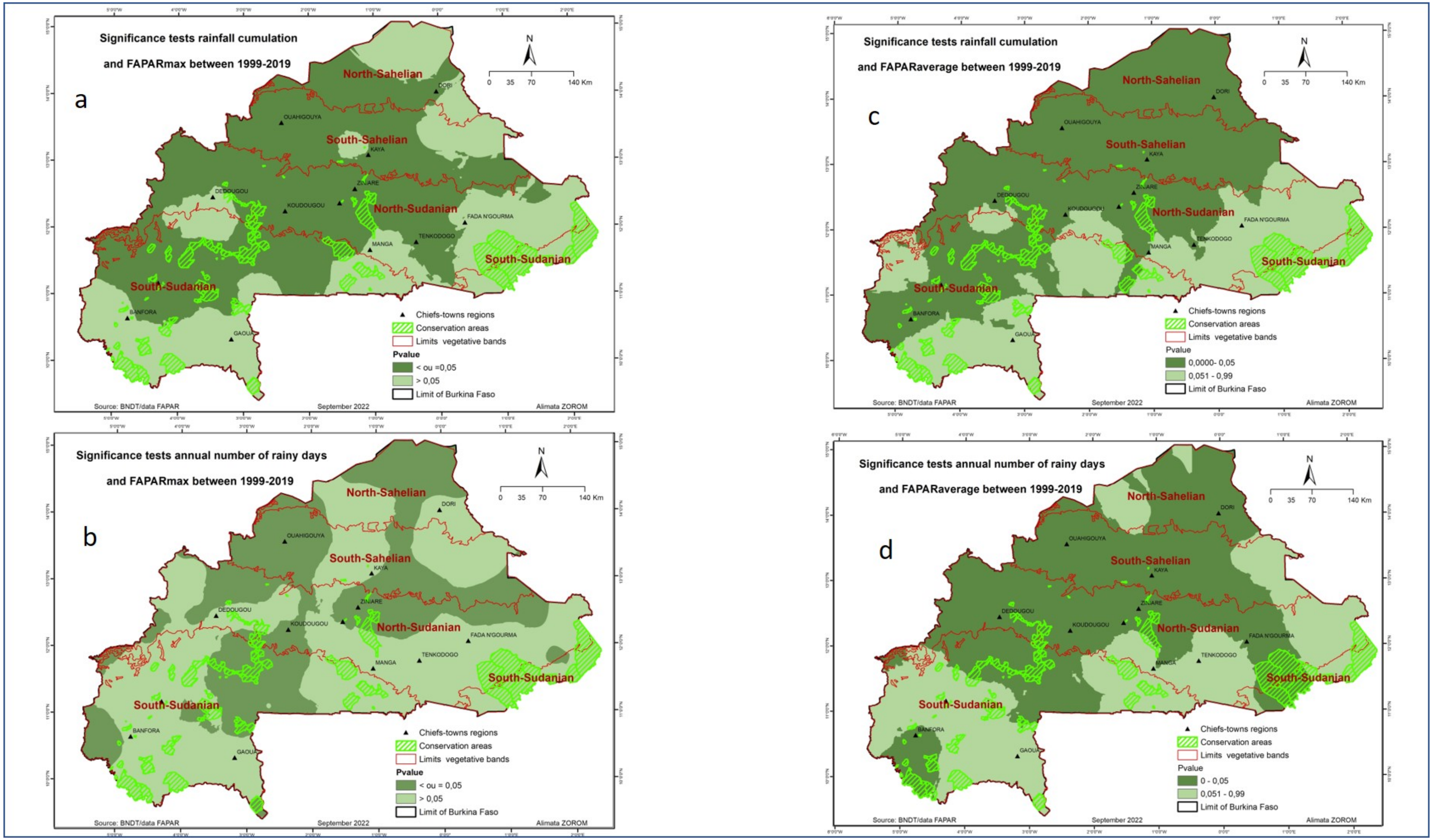


Figure 2 : Significance tests between precipitation and vegetation metrics

IV. Discussion

The relationships between precipitation dynamics and vegetation dynamics have been studied in this research. A strong correlation is established in the Sahelian phytogeographic domain and the north sector of the Sudanian domain. This could be explained by the fact that the correlated strong zones are those of the highest population densities (Ouagadougou, Koudougou, Ouahigouya) where the behaviour of the herbaceous layer follows the seasons. Low correlations are observed in the South, East and South West. This means that vegetation production is less dependent on rainfall accumulation in these areas. Moreover, this could also be explained by the fact that these areas are half dominated by perennial species with long vegetative cycles, the presence of tall trees and also the dominance of conservation areas. The results of this research on the relationships between precipitation dynamics and vegetation dynamics are corroborated by many authors in several regions of Africa at spatial and temporal scales. For example, in Mali and Niger during the period 1982 - 1985, [19] showed a significant and strong relationship between seasonal and interannual variations in precipitation and vegetation. In the Sahel, in the semi-arid zone, the correlation between NDVI and rain is higher because in this zone precipitation is the main constraint for vegetation growth [20].

The correlations between the average FAPARmax, the annual rainfall totals and the annual number of rainy days over the period 1999-2020 have been well established in Burkina Faso. The importance of the correlation varies according to the phytogeographical zones. The strongest correlations are observed in the Sahelian domain and in the north sector of the Sudanian domain. In the Sahelian domain, vegetation is dominated by herbaceous grasses whose development depends on the seasons. It is also a heavily anthropized area (agricultural activities, pastures). The North Sudanian sector is renowned for its high population density with strong urban development. Localities with high urban growth, with the exception of a few areas with classified forests, are weak in perennial plant species. However, the correlation between the number of rainy days and the FAPARmax is not well established. They are weak in the Sud-Sudanian sector and this could be explained by the dominance of large conservation areas and large trees. The regions represented in this area have low population numbers. These results confirm previous work using NDVI in the study of various regions of Sahelian Africa [19], [8], [9], [14], [11], [12], [13], [21]. Calculations of correlations between rainfall and vegetation metrics show a link between annual rainfall, the annual number of rainy days and vegetation. This result corroborates that of [6] with the NDVI index where he finds that the link between NDVI and spatialized rain is indisputable. The variation in the coefficients of correlation between FAPAR and precipitation would be due to population density, abundance of parks and reserves. [16] find that rainfall is not the only variable correlated to vegetation, but other factors such as the existence of classified forests, the presence of orchards, sacred places, the density of streams and their galleries, cemetery, recurrence and magnitude of bush fires. [15] also join [16] where they demonstrate that rainfall is not the only parameter that could influence vegetation dynamics, but there are other parameters such as soil type and plant floristic composition. [22] estimates that vegetation development is dependent on potential evapotranspiration (FTE) and relative air humidity (RH). Vegetation trends depend on location, drought situations and extreme rainfall from year to year [21]. [15] confirm that variation in rainfall affects vegetation dynamics.

In short, the South sector of the Sudanian domain, which almost in the various analyses of the correlations tests has non-significant values, shows that the high correlations observed are due to chance. Decoupling means that the relationship between rainfall and vegetation is not marked. In this case, other factors could serve as explanations for these weak correlations. Analysis of the results showed that the relationship between precipitation and vegetation was not evident in the south Sudanian sector where protected areas and Galerian forests are found. Precipitation is not the only vegetation growth factor in this region as noted [23]. Vegetation growth can be related to soil moisture and soil fertility. Soil fertility is rather a determinant of vegetation growth. The separation between precipitation and vegetation may also be due to the quality of the products used. In fact, the degree of cloud contamination of satellite images depends on latitudinal gradients. This means that the further we leave the north towards the south the more saturated the images and the sharpness is weak. This could be due to the existence of very contrasting or heterogeneous areas whose use of low-resolution images has limitations. The effect of images can be reduced through a smoothing algorithm, but often some algorithms do not work perfectly when the cloud effect is very large. Image accuracy is low in fields, pastures and conservation areas.

V. Conclusion

The objective of this article is to establish a link between rainfall and FAPAR. Correlations between precipitation and vegetation metrics are evident from this assessment, but these correlations are important across the country. These correlations are more pronounced in the Sahelian region and in the North Sudanian sector, where annual crop production is highly dependent on precipitation. In the south Sudanian sector, there is no correlation between the interannual dynamics of precipitation metrics and those of vegetation due to the predominance of perennial species which, in years of poor rainfall, contribute strongly to the weighting of plant production deficits.

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