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Rainfall Analysis for Agricultural Purposes in Thies Region, Senegal

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Abstract: *In rainfed conditions, crop success or failure is closely related to rainfall patterns. Assessment of rainfall variability is an integral part of water resources planning and management. This study is based on rainfall data from 3 weather stations over the period 1951-2017. Our approach is mainly structured according to visual and index examination. It is based on analysis of trends or changes in rainfall that is an important prerequisite for any agricultural planning. At the end of this study, it is noted that, given available information, current drought appears to be most important both in terms of duration and rainfall deficit it presents. Visual examination showed a high irregularity of rainfall and a general downward trend. This trend seems more remarkable in Mbour than Thiès and Tivaouane. Index examination showed that Thies had longest duration of drought and Tivaouane shortest. In terms of balance sheet, loss seems much more fatal in Mbour Thiès and Tivaouane. In terms of the drought probability occurrence, this examination showed that, Thies emerged as the most affected and Tivaouane as the least. These results highlight high vulnerability and significant drying up of study area.*

Keywords: *Climate Change, Drought Index, Rainfall Variability, Rainfed agriculture, Irrigated agriculture, Crop Production, Food security, Sustainable Development*

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I. Introduction

In many West African countries, agriculture plays a dominant role in the economy and the survival of populations. It contributes significantly to GDP, job creation and most foreign exchange earnings (Block and Rajagopalan, 2007). According to (Pareek, 2017) agriculture is the main source of food production and the main source of livelihood for 36% of the world's total labor force. He adds that in the densely populated countries of sub-Saharan Africa, 67% of the active population still live on agriculture. The success of this agriculture is closely linked to the availability and accessibility of water (Gunarathna and Kumari 2013, Maftei et al. According to (Awulachew et al., 2012, Diouf et al., 2018), natural rainfall is the main source of water for agricultural production (since irrigation covers very little cropland) and for soil moisture. The structure and quantity of these precipitations are largely determined by climatic factors (Dash et al., 2009). Any change in climate behavior necessarily affects rainfall patterns and, therefore, agricultural systems (Traore et al., 2018). In Africa, climate change has led to drought in Sahelian countries, which has led to severe rainfall decreases (in terms of quantity and frequency), piezometric levels and falling stream flows. (Fauchereau et al., 2003, Ahoussi et al., 2013). This is causing the rise in temperatures affecting the production of food crops, other important crops as well, and thus threatening food security, economic growth, the reduction of poverty of the populations in a large part of the regions arid and semi-arid (Ram et al., 2015). In Ethiopia, for example, rainfall variability resulted in a production deficit (20%) and an increase in the poverty rate (5%), which cost the economy more than a third of its growth potential (Hadgu and al., 2013). Climate variability in the opinion of (Brouder and Volenec 2008, Rashid and Rasul 2011) has a direct and adverse impact on food production and sustainable development in rainfed areas. According to (Pareek, 2017) climate change and agriculture are interrelated processes and besides the likely decline in food production, the nutritional quality of food can also be reduced, which will pose a nutritional security problem by 2100 According to (Goulden et al., 2009, World Bank, 2013), climate impacts on water resources will exacerbate the problems of population growth, land use, urbanization and hydropower generation in the coming decades and especially in developing countries. Thus, to understand this phenomenon of lack of water in all its facets, several symposia and meetings around the world are conducted (Kumar et al., 2010, Traore et al., 2018).

They aim to understand climate dynamics and to reflect on plans for reliable assessments of its negative impacts on natural resources and the quality of life of human beings with a view to developing mitigation, adaptation and adaptation strategies appropriate forecast for new environmental conditions (Conway et al., 2011). In addition, several authors have carried out studies on the variability of rainfall in West Africa (Lebel and Ali, 2009). All unanimously, have shown that the changing structure of precipitation and its impact on surface water resources are an important climate problem for today's society (Shiulee et al., 2013). The analysis of precipitation trends is part of the work undertaken by the FAO Project's meteorological service on the re-evaluation of water resources and demand (Partal and Kahya, 2006, Pashiardis and Michaelides, 2008). Thus, in the region of Thiès which is the subject of this study, precipitation is a limiting factor. They govern yields and determine the choice of crops that can be grown. Therefore, a thorough and detailed knowledge of rainfall patterns is an important prerequisite for agricultural planning. For this reason, rainfall analysis for agricultural purposes should include information on trends or changes in rainfall, the beginning, end and length of the rainy season, the distribution of rainfall throughout year and the risk of dry and wet periods (Karpouzos et al., 2010). This article aims to evaluate the rainfall variability of 3 agro-climatic zones in the Thies region. Detailed spatial data sets with 7 decades of information are used in this study. The data were made available to us by the National Agency of Civil Aviation and Meteorology (ANACIM). The choice of the Thies region is justified by the fact that rainfed agriculture occupies an important place in the economy, the quality of life, and the means of subsistence of the populations. Since some time, it is clear that agriculture once promising becomes more and more doubtful in terms of dynamism and production. Therefore, the availability of adequate indicators for a revalorization of agriculture in modified climate scenarios is of considerable importance.

II. Materials and Methods

II. 1. Study area

Thiès is one of the 14 administrative regions of Senegal located in the western part 70 km from the capital Dakar (ANSD, 2009). It lies between latitude 14 ° 50'03"Nord and longitude 17 ° 06'21 " West and covers an area of 6,601 km2. The region of Thies is limited to the North by the region of Louga, to the South by the region of Fatick, to the East by the regions of Diourbel and Fatick and to the West by the region of Dakar and the Atlantic Ocean (Fig .1) (CEDA, 2006). It comprises 3 departments, 26 communes, 49 rural communes and 1766 villages housed in 195790. Its population is 1788864 inhabitants, or 271 inhabitants / square kilometer and distributed between Thiès departments (667814 inhabitants), Mbour (668 878 inhabitants) and Tivaouane (452172 hbts) (ANSD, 2017). With an urbanization rate of 49%, the region has a young population, 52.3% of the population is under 19, of whom 27.2% are in the age group of zero (0) to five (5 years). According to sex, the population is composed of 50.1% of men and 49.9% of women. The economy is essentially based on agriculture, fishing, tourism, industry, mining, handicrafts and trade. Among the productive sectors, agriculture occupies an important place in the economic and social life of the Thiès region. It occupies the majority of the regional population and is the main activity in rural areas. The Thiès region is a major agricultural production center thanks to its numerous hydraulic and soil potential (ANSD, 2015). It mainly comprises three zones with agricultural vocation: (i) the Niayes coastal zone (with market gardening and fruit production); (ii) the central zone (with groundnut, arboricultural and cassava vocation) and (iii) the southern zone (with market gardening and food production). However, it is clear that agricultural production is dependent on rainfall and availability of inputs. The climate of the region is subject to the influence of the maritime trade winds and the harmattan. It is Sudano-Sahelian type in the South and Southeast; Sahelian North and North East. The western zone, meanwhile, has a sub-climate. The rainfall record shows a rainfall that runs from June to October. The records show average rainfall ranging from about 300 to 800 mm (ANSD, 2018). The lowest monthly temperature is recorded in February; the highest is recorded in September. The region is characterized by tropical ferruginous soils with sandy, sandy-clay and clay-humus texture; and hydro morphic soils with a humic texture. The vegetation consists mainly of shrub savanna, filao and classified forests. From a water point of view, the region has significant groundwater, surface water and relatively good quality well water in some areas (Diop, 2002).

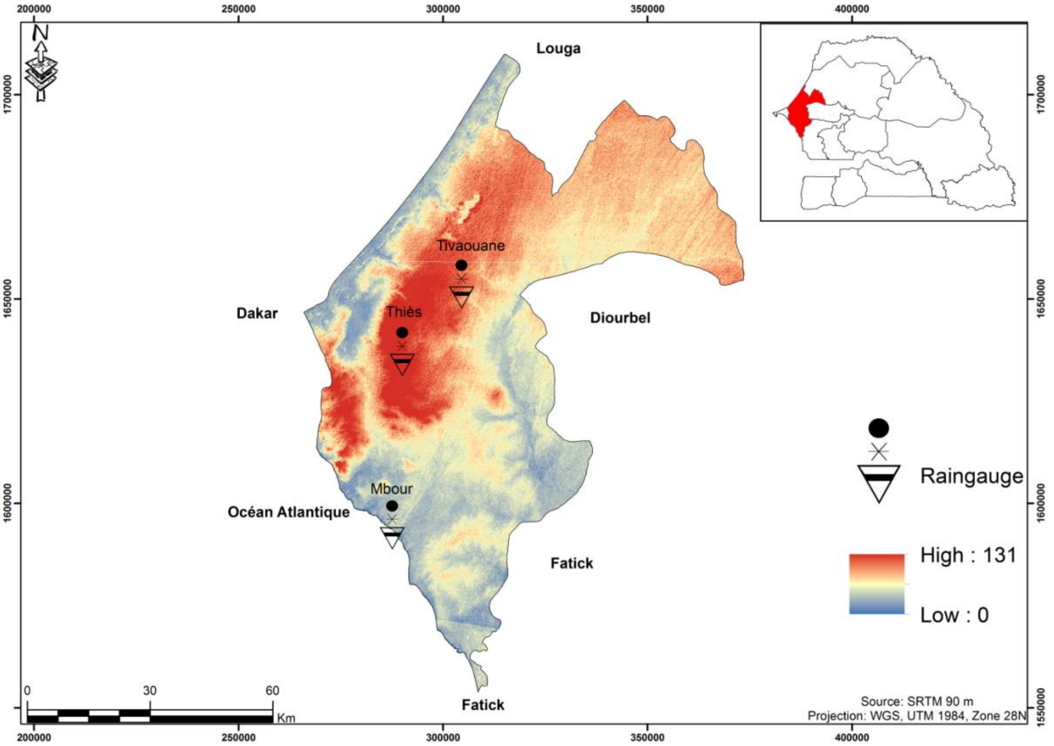

Fig.1. Location of study area

II. 2. Visual examination

Visual analysis is a procedure to highlight certain factors that explain the correlation and dependence between the variables selected. It starts with data and is based on observation logic (Tossou et al., 2017). The explorer looks at his data from every angle, tries to highlight structures and, where appropriate, formulates plausible hypotheses. It does not attach great importance to the optimality of the tool used but rather to its good behavior in most situations (Doumouya et al., 2016). Climatic parameters such as rain, temperature, evapotranspiration ... at all scales are very often exploited. This approach consists in representing the histograms (or graphs) of all the observations as well as the trend curves to circumscribe visually their evolution during the period studied. A judicious and rigorous interpretation of the results makes it possible to obtain a global vision and possibly detect forms of irregularities (Diouf et al., 2016).

II. 3. Index examination

Il existe dans la littérature plusieurs indices permettant de déterminer le seuil de la sécheresse climatique, et de définir les classes d'appartenance de cet événement en fonction de sa sévérité. Ils consacrent l'importance du temps dans l'analyse de la disponibilité des ressources en eau.

III. 3.1. Rainfall deficit index

To locate a rainfall in a long series of rainfall records, we use the deviation proportional to the average It allows to visualize and determine deficit situations and their succession .It is expressed by the relation (1) (Elbouqdaoui et al., 2006).

$$I_E = \frac{P_i}{\overline{P}} - 1 \quad (1)$$

With P_i : rainfall of the year i; $\overline{P}$: interannual rainfall average over the reference period.

Depending on the positive or negative values of the index, a drought or moisture situation can be identified (Stour and Agoumi, 2009). A year is qualified as wet if this index is positive for dry when it is negative (Table 1) (Jouilil et al., 2013).

Table1. Organization of years according to rainfall deficit index values

If $I_E > 0$	humidity ;
If $I_E < 0$	drought;

II. 3.2. Rainfall standardized index

This index is used to observe and analyze the inter and intra annual variability of rainfall data (Rosine et al., 2014). It highlights surplus and deficit periods within a time series. In addition to being powerful and flexible, the standardized index of rain has the advantage of being able to determine the water deficit throughout the season and the year (Elbouqdaoui et al., 2006). It takes into account the importance of time in analyzing the availability of water resources (Ali and Lebel, 2009). Its choice is justified by: (i) its applicability to all hydrometeorological data at different time scales; (ii) its ability to quickly detect drought situations and assess their severity; its strong use by climate experts around the world (Hadgu et al., 2013). It mathematically given by equation (2).

$$I_A = \frac{P_i - \overline{P}}{\sigma} \qquad (2)$$

With P_i : rainfall of the year i; $\overline{P}$: interannual rainfall average over the reference period and σ : corresponding standard deviation.

This index defines the severity of drought in different classes (Table 2). In general, the negative values indicate a deficit situation the positive a surplus situation (Faye et al., 2015).

Table 2. Organization of years according to Standardized Rainfall Index values

If $I_A > +2$	extreme humidity;
If $1 < I_A < 2$	strong humidity;
If $0 < I_A < 1$	moderate humidity;
If $-1 < I_A < 0$	moderate drought
If $-2 < I_A < -1$	strong drought
If $I_A < -2$	extreme drought

II. 4. Data and application

This study focuses on the Thies region in the west of the country. It is based on the annual rainfall data of the Thies Mbour and Tivaouane meteorological stations over the period from 1951 to 2017. The data were made available to us by the National Agency of Civil Aviation and Meteorology (ANACIM). The choice of rainfall stations was dictated by the need for good quality data over a long period without gaps. The choice of precipitation among climatic parameters meets a practical criterion: the accessibility to data, the fact that precipitation is probably the main cause of the temporal variability of water conditions and that it is the main one. source of water for agricultural production. In this region, agriculture occupies an important place in the survival of the populations. However, it is clear that agricultural production is dependent on rainfall and availability of inputs. The success of agricultural production has far-reaching consequences, ranging from the survival of subsistence agriculture to the state of the economy in this region. In recent years, production in the region, including all speculations, has fallen significantly from 13.7% to 47.2%. This situation has a considerable impact on the stability of the food system and the state of the economy in this part of the country. In this context, the analysis of weather time series is more necessary than ever with increased vigilance. Our approach is essentially structured according to 2 components: a component relating to the visual examination and that relating to the index examination. Our concern at this level is to extract all the information that can inform or build rights holders on the climatic hazards of this period. Such studies are important for the re-evaluation of water resources and demand for agricultural planning.

✓ **section relating to visual examination**

For this part, we made a graphical representation of the mean annual rainfall of the three stations by adding on the same graphs the interannual moving average curve. The ensemble allowed us to visualize the distribution of precipitation on an annual scale, the direction of the trend and to judge its significance or not.

✓ **section relating to index examination**

For this component, we calculated the standardized indices of rainfall and rainfall deficit on an annual scale. Then, using the reference tables 1 and 2, we highlighted the different situations of drought and humidity that crossed the region of Thiès during this period. Finally, we assessed the frequency or probability of occurrence of each of the situations encountered; this allowed drawing a balance sheet. The ensemble highlighted the level of severity of droughts and humidities experienced in this area over the period 1951-2017. This study aims to provide information to water resource planners and policy makers on the implementation of water conservation or mitigation measures where appropriate.

III. Results and Discussion

III. 1. Visual examination

Figures 2a, 2b and 2c show the evolution of annual rainfall and their moving averages at the Thiès (fig.2a), Mbour (fig.2b) and Tivaouane (fig.2c) stations for the period 1951- 2017. This is to visually circumscribe the distribution of annual rainfall inflows over the period studied and to make the first impression on the general trend. The reading of the different figures shows a strong irregularity of rainfall for all three stations. The analysis of the moving averages of these rains shows a general downward trend. The annual rainfall contributions are maximum in 1957 in Thies and in 1958 in Mbour and Tivaouane; they reached their minimums in 1972 for the three stations. This downward trend seems more remarkable in Mbour than in Thiès and Tivaouane.

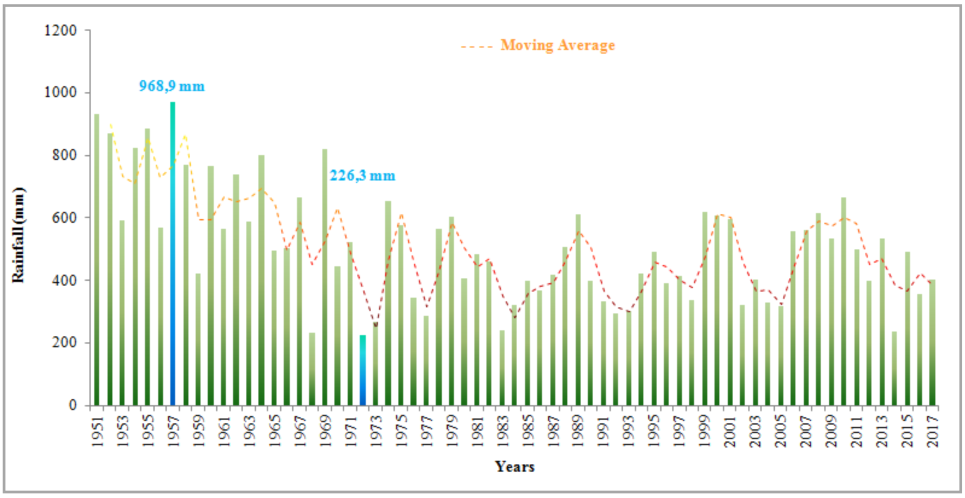

Fig.2a. For Thies station

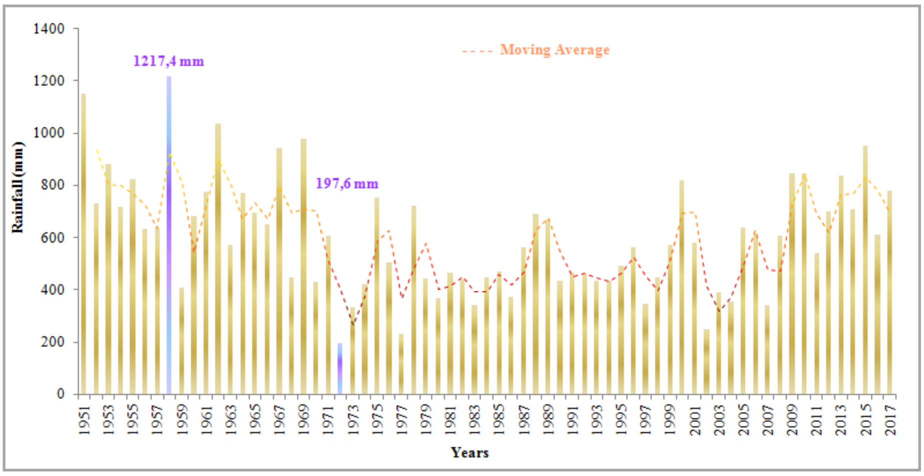

Fig.2b. For Mbour station

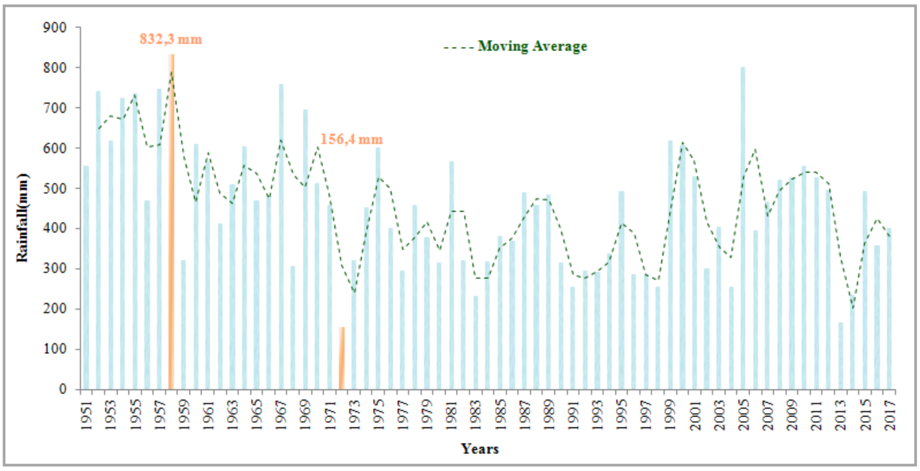

Fig.2c. For Tivaouane station

III. 2. Rainfall deficit index

We present in fig.3a, 3b and 3c the evolution of the index of rainfall deficit respectively at the station Thiès (fig.3a), Mbour (fig.3b) and Tivaouane (fig.3c) over the period 1951 -2017. The analysis of the different figures using Table 1 highlights 30 wet years and 37 dry years for the Thiès station (Fig. 3a); 33 wet years and 34 dry years for the Mbour station (Fig.3b) and 36 wet years and 31 dry years for the Tivaouane station (Fig.3c). In terms of dry episodes, the Thiès resort had the longest duration and the shortest Tivaouane. The maximum (968.9mm) was reached in 1957 and the minimum (226.3mm) in 1972 for the Thiès station (fig.3a); for the Mbour station, the maximum (1217.4mm) is reached in 1958 and the minimum (197.6mm) in 1972 (fig.3b) and for the Tivaouane station, the maximum (832.3mm) is reached in 1958 and the minimum (156.4mm) in 1972 (fig.3c). In terms of balance sheet, the Thiès station recorded a loss of (-742.6 mm), that of Mbour a loss of (-1019.8 mm) and for Tivaouane, we have a loss of (-675.9 mm) ; this shows that during the 67 years analyzed, the drop in rainfall intensity, seems much more fatal in Mbour Thiès and Tivaouane. The analysis of the trend curves confirms this decrease in rainfall for all three stations, given the negative slope values. In sum, it appears that deficit periods are more extensive in space and persist in time than surplus periods.

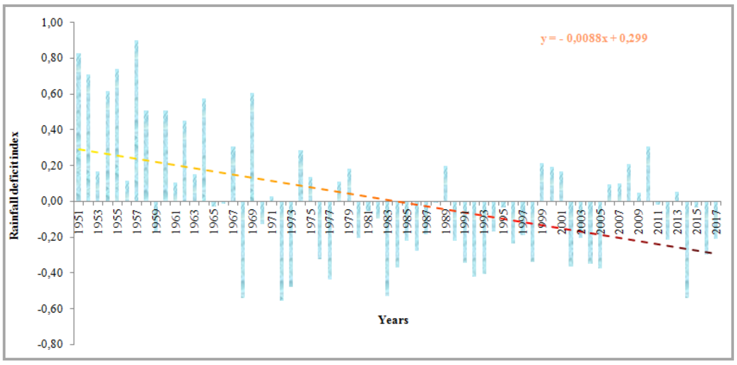

Fig.3a. For Thies station

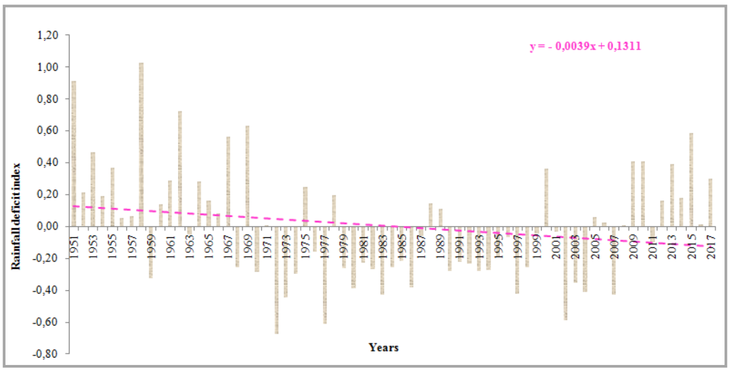

Fig.3b. For Mbour station

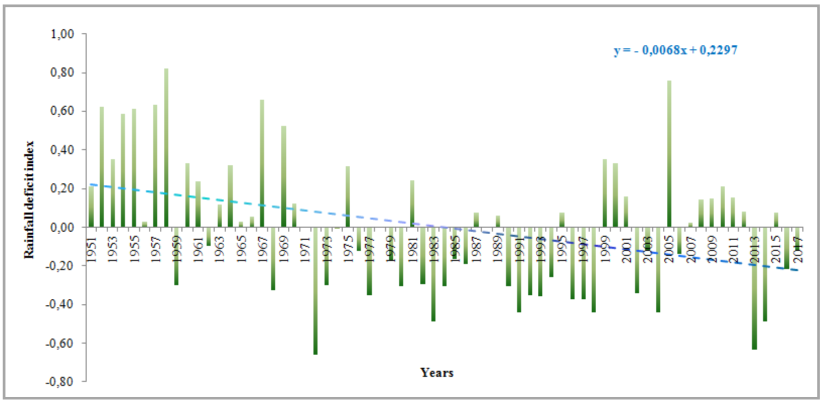

Fig.3c. For Tivaoune station

III. 3. Rainfall standardized index

Figures 4a, 4b and 4c respectively show the evolution of the standardized index of rain at the stations of Thiès (fig.4a), Mbour (fig.4b) and Tivaouane (fig.4c) over the period 1951-2017. The analysis of these figures on the basis of Table 2 shows 2 years of extreme humidity, 8 years of high humidity, 20 years of moderate humidity, 29 years of moderate drought and 8 years of severe drought (Fig. 4a); 1 years of extreme humidity, 5 years of high humidity, 27 years of moderate humidity, 31 years of moderate drought and 3 years of severe drought (fig.4b); 8 years of high humidity, 28 years of moderate humidity, 29 years of moderate drought and 2 years of severe drought (fig.4c). The year 1957 appears as the wettest 1972 as the driest for Thies station, for the Mbour and Tivaouane stations, 1958 is the wettest year and 1972 the driest. The probability of occurrence of extreme humidity is 3% in Thiès, 1.5% in Mbour and 0% in Tivaouane. The probability of occurrence of high humidity is 11.9% in Thiès and Tivaouane and 7.5% in Mbour. The probability of occurrence of moderate humidity is 29.9% in Thiès, 40.3% in Mbour and 41.8% in Tivaouane. The probability of occurrence of moderate drought is 43.3% in Thiès and Tivaouane and 46.3% in Mbour. The probability of occurrence of the severe drought is 11.9% in Thiès, 4.5% in Mbour and 3% in Tivaouane. In total, Thiès (55.2%) seems the most affected by the dry sequences and Tivaouane (46.3%) the least affected. These results highlight the great vulnerability and the increased drying up of the Thiès region over the period 1951-2017. This corroborates well with the previous results.

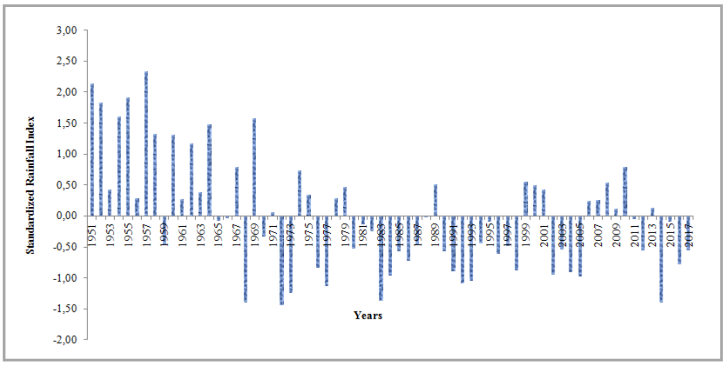

Fig.4a. For Thiès station

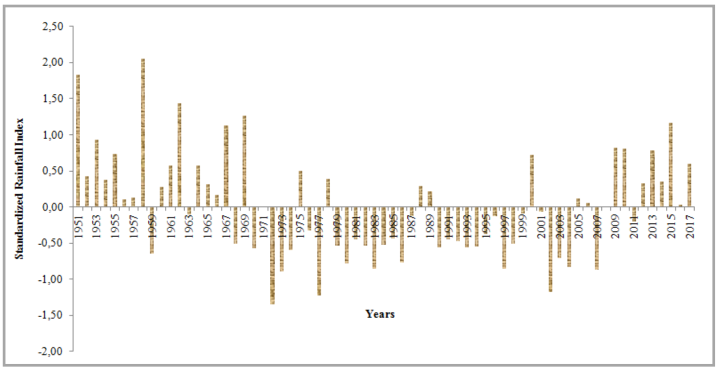

Fig.4b. For Mbour station

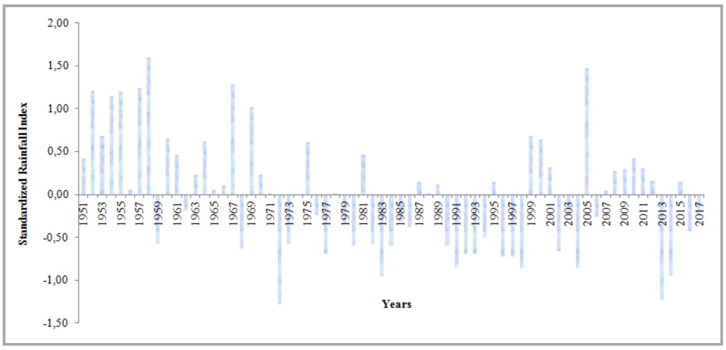

Fig.4c. For Tivaoune station

IV. Conclusion and recommendation

Changing structure of rainfall and its impact on surface water resources is an important climate problem for today's society. Thus, trend analysis from historical data is one of the areas of active interest to study rainfall variability. This is an important prerequisite for the re-evaluation of water resources and requires for any agricultural planning. This study focuses on the Thies region in the west of the country. It is based on annual rainfall data from the Thies Mbour and Tivaouane meteorological stations over the period from 1951 to 2017 and acquired by the National Agency of Civil Aviation and Meteorology (ANACIM). Our approach is essentially structured according to 2 components: a component relating to the visual examination and that relating to the index examination. Our concern at this level, is to extract all the information that can inform or build rights holders on the climatic hazards of this period. For the visual examination component, a graphical representation of the annual rainfall of three stations was made by adding on the same graphs the interannual moving average curve. With regard to the index component, we have calculated the annual standardized indices of rainfall and rainfall deficit; we highlighted the different drought and moisture situations that the Thiès region experienced during the study period. We also assessed the frequency or probability of occurrence of each of the situations encountered and generated a balance sheet in terms of contributions or losses. The ensemble highlighted the level of severity of droughts and humidities experienced in this area over the period 1951-2017. At the end of this study, the results obtained are, on the whole, convincing, telling and promising. Thus, the visual examination analysis showed a high irregularity of rainfall for all three stations. The moving average analysis showed a general downward trend. Annual rainfall inflow peaked in 1957 in Thies and in 1958 in Mbour and Tivaouane; they reached their minimums in 1972 for the three stations. This downward trend seems more remarkable in Mbour than in Thiès and Tivaouane. The analysis of the rainfall deficit index highlighted 30 wet years and 37 dry years for the Thiès station; 33 wet years and 34 dry years for the Mbour station; 36 wet years and 31 dry years for Tivaouane station. In terms of dry episodes, the Thiès resort had the longest duration and the shortest Tivaouane. The maximum (968.9mm) was reached in 1957 and the minimum (226.3mm) in 1972 for the Thiès station; for the Mbour station, the maximum (1217.4mm) is reached in 1958 and the minimum (197.6mm) in 1972 and for the Tivaouane station, the maximum (832.3mm) is reached in 1958 and the minimum (156 , 4mm) in 1972. In terms of balance sheet, the Thiès station recorded a loss of (-742.6 mm), that of Mbour a loss of (-1019.8 mm) and for Tivaouane, there is a loss of (-675.9mm); this shows that during the 67 years analyzed, the drop in rainfall intensity, seems much more fatal in Mbour Thiès and Tivaouane. The analysis of the trend curves confirmed this decrease in rainfall for all three stations because of the negative slope values. In sum, it appears that deficit periods are more extensive in space and persist in time than surplus periods. The analysis of the standardized rain index showed 2 years of extreme humidity, 8 years of high humidity, 20 years of moderate humidity, 29 years of moderate drought and 8 years of severe drought for the station. Thies; 1 year of extreme humidity, 5 years of high humidity, 27 years of moderate humidity, 31 years of moderate drought and 3 years of severe drought for the Mbour resort; 8 years of high humidity, 28 years of moderate humidity, 29 years of moderate drought and 2 years of severe drought for the Tivaouane station. The year 1957 appears as the wettest 1972 as the driest for Thies station, for the Mbour and Tivaouane stations, 1958 is the wettest year and 1972 the driest. The probability of occurrence of extreme humidity is 3% in Thiès, 1.5% in Mbour and 0% in Tivaouane. The probability of occurrence of high humidity is 11.9% in Thiès and Tivaouane and 7.5% in Mbour. The probability of occurrence of moderate humidity is 29.9% in Thiès, 40.3% in Mbour and 41.8% in Tivaouane. The probability of occurrence of moderate drought is 43.3% in Thiès and Tivaouane and 46.3% in Mbour. The probability of occurrence of the severe drought is 11.9% in Thiès, 4.5% in Mbour and 3% in Tivaouane. In total, Thiès (55.2%) seems the most affected by the dry sequences and Tivaouane (46.3%) the least affected. These results highlight the great vulnerability and the increased drying up of the Thiès region over the period 1951-2017. This corroborates well with the previous results. This study shows that, given the information available, the current drought appears to be the most important both in terms of duration and the rainfall deficit it presents. These results would, in our opinion, alert the authorities to the need for new policies to reduce the dependence on rainfed agriculture. Faced with this growing water stress, the availability of adequate water for irrigation is of considerable importance. Solutions such as water control based on the mobilization and storage of groundwater and groundwater and the choice of low-water speculation and regulated and well-structured irrigation techniques should be undertaken for boost irrigated agriculture to the detriment of rainfed agriculture. Otherwise, the local nutritional self-sufficiency long proclaimed by the authorities, will be only utopia.

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