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Spatial and temporal distribution of rainfall in agro-climatic zone of Fatick region, Senegal

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Abstract The present study attempts to analyze changes occurring in spatial and temporal distribution of rainfall at the Fatick region to provide information on its long-term variability. It is based on rainfall of two raingauges during a period extending from 1981 to 2016. In this respect, our procedure is essentially structured in 3 components: Standardized anomaly index, precipitation concentration index and coefficient of variation computation. The results obtained are very informative. Considering standardized anomaly index, results demonstrated the intensity and frequency of drought vis-a-vis for wet years. Indeed, frequency occurrence of below normal rainfall increased over the study period. In this regard, 70% of the years have recorded below long term average at Ndofane station and 59 % in that of Toubacouta. Regarding Precipitation Concentration Index (PCI), results showed PCI value greater than 20% both for the two stations. So, results are grouped under high and very high concentration which indicates poor monthly distribution of the rainfall. Such values correspond to climate with marked monthly contrasts in rain intensity. Moreover, results on seasonal scale, shows irregular distribution, seasonal and highly seasonal years both for the two stations. It emerges from this analysis that irregularity is more pronounced at Ndofane than Toubacouta. Considering variation coefficient, results indicate highly distribution of rainfall over the entire study period (1981-2016) for Toubacouta. For Ndofane, results show highly distribution of rainfall occurring the period 1981-2001 and 2004-2016. For years 2002 and 2003, the distribution is homogeneous. These results show that variability is more pronounced at Toubacouta than Ndofane. Ultimately, rainfall in Fatick has been subject to irregularity and some general tendency to decrease. In this regard, deficit periods are slightly more extended in space and a little bit more persisting in time than the surplus periods. Such results suggest the need for designing appropriate agronomic and water management strategies to offset the negative impacts of rainfall variability in the Fatick region.

Keywords Annual rainfall, Rainfall trend, Rainfall variability descriptors, Food system stability, Sustainable and productive agriculture, Agro-climatic regions, Senegal

1. Introduction

In many developing countries, agriculture plays a dominant role in the economy, contributing to employment creation, GDP and the majority of foreign exchange earnings [1-2]. The success of agricultural production, has therefore, important implications for the survival and livelihood of farmers. This success depends on the water availability [3]. From [4]'s opinion, natural rainfall is the main source of water for crops production since irrigation covers less than 5% of the cultivated land in these categories of countries. According to [5-6] , rainfall is one of the most important climate variables directly affecting the availability of water resources. Nowadays it is strongly admitted that there is a close complicity between climatic events and the quantity of rainfall in any part of the world [7-8]. So, any change in climatic behavior has a great influence on the precipitation regime such as its decline, thus limiting the availability of water [3-9]. According to [10], climatic events are mainly a blend of several factors that are naturals and/or anthropic orders. [11] adds that climate change is global phenomena and occurring continuously since the earth came into existence. According to [12-13] climate fluctuations are mainly translated by a decrease in the quantity of rainfalls, along with their frequency in time and space, a change in timing of occurrence and rainfalls seasonal variability changes according to the response to some watersheds thus causing temperature rise. The latter may, according to [14], harm the production of subsistence crops, along with other important crops, and thus threaten the food security of populations living in the major part of arid and semi-arid regions. [15-16-17] add that the existence of an increasing or decreasing trend in hydrological time series can also be explained by the changes of the factors that influence the rainfall. [11-18] stipule that climate changes have significant impacts on alteration in soil moisture conditions and levels, destruction of soil minerals, loss of soil fertility etc. Such situation leads to declining in food production; nutritional quality of food may also be reduced raising a concern for nutritional security [19-20]. [21-22] estimate that poor communities such Africa and Asia are more concerned due to their limited adaptation capacities, weakness of agricultural equipment, no training for farmers, fragility of ecosystems and their great dependence to water resources and rainfall-related agricultural production systems. [15-23-24] think that West African states are more troubled due to the accrued sensitiveness to extreme situations (floods, drought) which frequently cause massive population displacements, economic standstill, poverty, social inequalities (which could lead to civil wars) ,famine and human lives losses. [25-26] predict reported that the impact of future climate change on hydrographic fresh water systems will amplify problems caused by other constraints such as population growth, changing economic activity, changes in land use and level of urbanization and in addition, the water demand (irrigation, household consumption, hydropower) will increase in the coming decades. [27] push the nail saying that future climate change would influence all characteristics of rainfall in terms of intensity, frequency and duration. To address such situation it is imperative to take some measures in order to slow down the pace of that evolution and to eventually mitigate or adapt to its increasingly visible negative impacts [28]. It is for these reasons that climate and increased climate variability have recently become a pressing issue in various political forums on development, environment, etc at the national, regional, and international levels [29]. Rainfall is a vital meteorological factor, usually selected as representative variable to directly reflect and predict global climate change in many studies [30-31]. The optimum time and space scales for rainfall are not well studied in the local domain and therefore it becomes important for one to understand the dynamics of the rainfall seasonally and annually [32]. West Africa in general and Senegal in particularly, have often shown rainfall variability and associated droughts leading to food shortages.[33] think that changes in the rainfall regimen and its impact, is an important climatic problem which need to be treated on priority. [34] suggests the there is a need for detailed analyses of the regional and sub-regional variability in precipitation. Detailed spatial datasets having multiple decades of information are required to carry out this kind of a study [35]. The current document deals with the Fatick watershed, notably in its low valley, in the central part of Senegal. In this area, agriculture depends strongly of on climate behavior. This dependency is indicated by the fact that cultivation in mostly rain fed area of the total cropped area is dependent on uncertainties of monsoon. Therefore, climate change can impact directly on food security through food system stability. In this region, agriculture is important for food security in two ways: it produces the food people eat; and it provides the primary source of livelihood. At the same time, sustainable agricultural systems aim to develop strategies to mitigate the negative impacts of climate change and variability. Unfortunately, this region is subject to several threats (desertification, productivity losses, etc) and no major decision has so far been undertaken in this direction. The objective targetted in this paper is to assess changes occurring in the spatial and temporal distribution of rainfall with 36-years database of monthly precipitation for identifying the annual distributions, variations and trends in agro-climatic zone of Fatick watershed, Senegal. Such analysis provides information for any reflection related to the understanding of hydrological processes and key elements affecting water availability in this area. So, Analysis of the standardized anomaly index, precipitation concentration index and coefficient of variation were carried out. The slope values obtained from linear regression was also examined. The results obtained are very informative.

2. Materials and Methods

2.1. Study Area and Data

The region of Fatick is located in the western part of Senegal between latitude 14.37 N and longitude -16.13 W. It is limited to the East by the Kaolack region, to the West by the Atlantic Ocean, to the North by the region of Diourbel, in the North West by the region of Thies, in the North East by the region of Louga and in the South by the Republic of Gambia [36]. After the 2008 reforms, the region has three departments and nine districts, 28 rural communities and nine (9) communes over an overall area of 6685 km^2. Its population is estimated at 714 389 inhabitants, or 5.3% of the national population and housed in 58 454 households. The population, mainly composed of women (50.5%), is characterized by its youth, 47.6% of the population are under 15 years old [37]. Agriculture, livestock and fishing are the main resources, but, although under-exploited, the tourism potential in the Fatick region is rich and diverse. However, agriculture remains the main economic activity and occupies nearly 90% of the active population. It is extensive and highly dependent on rainfall. This activity focuses on cash crops (groundnuts, cotton, sesame, watermelon, vegetable and fruit crops) and food crops (millet, rice, maize, cowpeas) and is still practiced by 98.5% of households at regional level. 60.6% of the national level. It should be noted, however, that a good part of the land is salty (0.5 to 3 g/l) and rich in fluorine (2 mg/l), and is therefore unfit for cultivation and unsuitable for farming. These lands, which represent 27% of the regional area, constitute a major constraint for the development of the sub-sector [38]. The development and development of the Territory is a big challenge for the Fatick region. Indeed, it is facing a disarticulation of its space, a disparity of infrastructure and basic equipment, a deterioration of the environment very heavy on sustainable exploitation of all its opportunities. From climatic point view, the region is bathed in a natural environment characterized by a tropical Sudanian-type climate marked by a Sudanese Sahelian variant and a Sudano-Sahelian variant. It is also influenced by the maritime climate on the coastal part of the departments of Foundiougne and Fatick. During the normal years (1931-1985), the rainfall varies between 600 and 900 mm. In recent years it was more irregular, varying between 400 and 600 mm .The rainy season is from June to October with maximum intensity in August and September, and the dry season from November to May. Minimum temperatures ranged from a little less than 20.7 ° C to a little over 21.9 ° C, while maximum temperatures ranged from 35 ° C to almost 37 ° C. The sunshine was around 7 hours per day. The main winds that sweep the region are: The Harmattan, hot and dry, which blows over the entire north and north-east; the maritime trade wind present in the coastal zone and the Monsoon blowing between April and October [36]. From soil point view, the region reports 3 to 4 types of soil that vary according to ecological zones: tropical ferruginous soils, hydro morphic soils of the valleys, soils halo morphs (saline soils) and mangrove soils observed in the islands and estuaries. From a hydrographic point of view, the region's water resources consist of surface water and groundwater. Surface waters consist of the perennial rivers of Sine, Saloum, Gambia River and their tributaries. There are also temporary streams consisting of backwaters and ponds. The groundwater consists of Maestrichtian, Paleocene, Eocene and continental aquifers. Vegetation cover is mainly characterized by rainfall, human activities and nature. It consists of 4 large plant formations (savannah and wooded savannah, ...) .The vegetation cover is mainly characterized by rainfall, anthropogenic activities and the nature of soil or bedrock [38]. The wildlife potential is composed of terrestrial fauna, sedentary birds and migratory birds. This study deals with the Fatick River Basin, notably in its low valley, in Senegal. It is based on rainfall data of four raingauges during a period extending from 1981 to 2016 acquired from the database of ANACIM (National Agency of Civil Aviation and Meteorology).

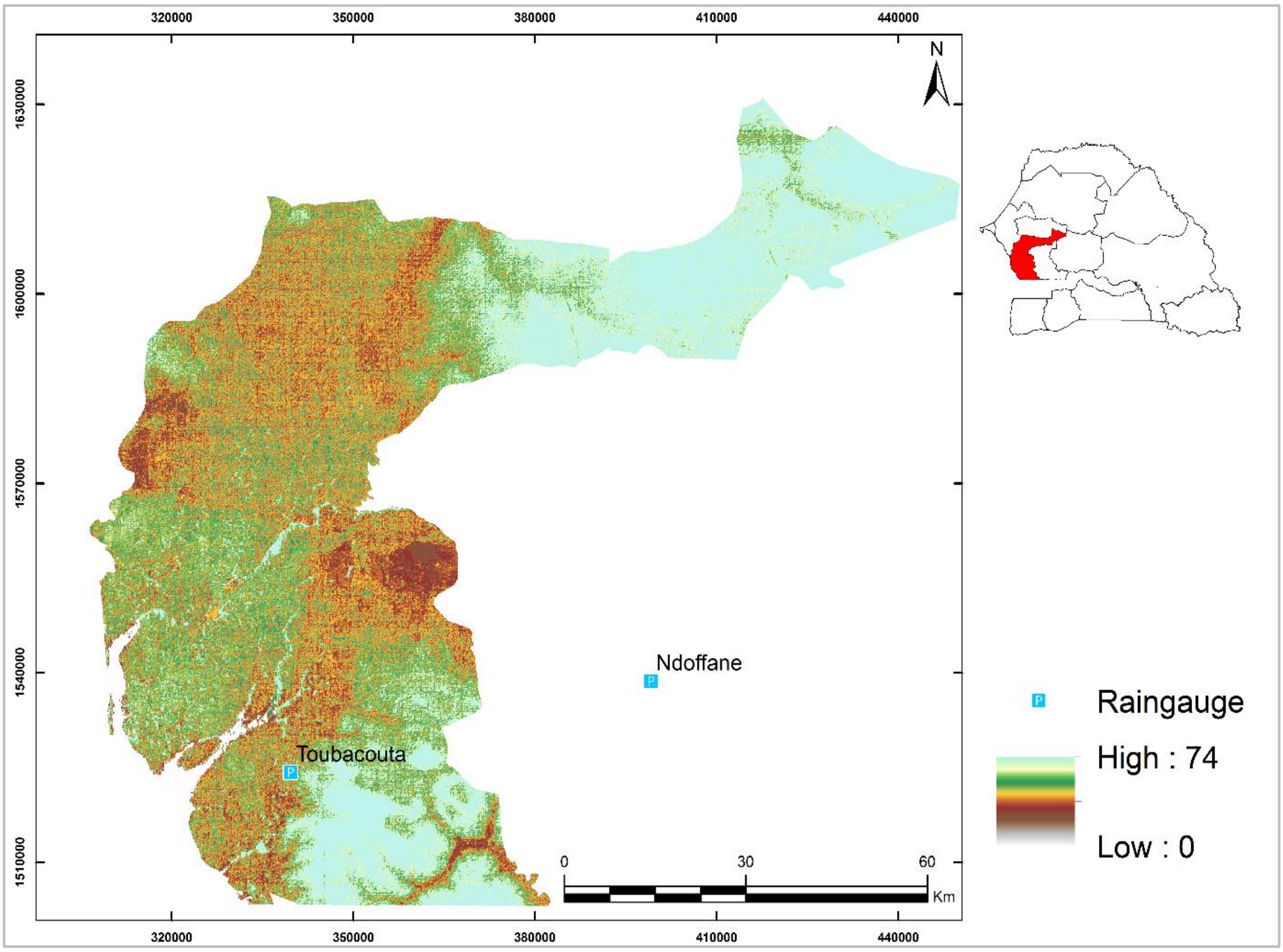

Figure 1: Localization of study area

2.2. Variability analysis

In climatology, Standardized anomaly index, precipitation concentration index and coefficient of variation were very often used as descriptors of hydrometeorological data variability [2]. In this study, we limited ourselves to annual rainfall data because of their importance for climatic phenomena.

2.2.1. Standardized anomaly index

Standardized Anomaly Index (SAI) is used to examine the nature of the trends also makes possible the determination of the dry and wet years or month in the record. This index is simple, powerful and flexible both based on hydrometeorological data at any scale [2-39]. The choice of that index is justified by its capacity to rapidly detect situations of drought and assess their acuteness. It is also highly recommended by climatologists due to the fact that it is less complex than many others drought index [3]. From annual rainfall scale point view , this index is calculated as the difference between the annual total of a particular year and the long term average rainfall records divided by the standard deviation of the long term data as shown in equation (1) [23].

$$Z_i = \frac{P_i - \bar{P}}{\sigma} \qquad (1)$$

Where, Z is standardized rainfall anomaly; X_i is annual rainfall of a particular year; $\bar{X}$ is mean annual rainfall over a period of observation and σ is the standard deviation of annual rainfall over the period of observation. According to [40], the Standardized Anomaly Index has the advantage to be able to determine the water deficit throughout the season and throughout the year. According to [41] year or month is wet, when the index value is positive, i.e. the annual or monthly rainfall is higher than the average; year or month is dry when the index value is negative, i.e., annual or monthly rainfall is less than average . A normal year or month is a period during which, the annual or monthly rainfall is sensibly equal to the average annual rainfall, i.e., the index value is equal to zero [42]. With the values of this index, we can meet according to [24] five categories of rainfall years:

If $Z_i > +2$: extremely wet year;

If $1.5 < Z_i < 1.99$: wet year;

If $1 < Z_i < 1.49$: moderately wet year;

If $-0.99 < Z_i < 0.99$: normal year;

If $-1.49 < Z_i < -1$: moderately dry year

If $-1.99 < Z_i < -1.5$: dry year

If $Z_i < -2$: extremely dry year

This index has the advantage to be able to determine the water deficit throughout the season and throughout the year [43].

2.2.2. Precipitation Concentration Index

One of the most used indexes as descriptors of rainfall variability is precipitation concentration index (PCI) [44-45]. This index originally proposed by [46] and modified by [47], is expressed on an annual scale according to Equation (2). According to [48], it is proposed as an indicator of rainfall concentration, rainfall erosivity and monthly rainfall heterogeneity. [49] add that two different procedures can be adopted to assess this index: PCI can be estimated by the number of average monthly rainfall data or calculated from the year set and then as the average over several years.

$$A_k = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} * 100 \qquad (2)$$

Where, P_i is the rainfall amount of the *ith* month.

According to [46] classification: i) PCI values below 10 represent a uniform precipitation distribution (i.e., low precipitation concentration); PCI values from 11 to 15 denote a moderate precipitation concentration; values from 16 to 20 indicate irregular distribution and values above 20 represent a strong irregularity of precipitation distribution (i.e., high precipitation concentration). This index has the advantage to provide information on long-term total variability in the amount of rainfall received [18-50].

2.2.3. Coefficient of variation

The coefficient of variation is a measure of dispersion that characterizes the spread of a series of data in relation to the average: the lower it is, the more the data are grouped around the mean and the larger it is, the more data are scattered [45]. In this study, coefficient of variation (CV) was calculated to evaluate the variability for each year of the rainfall and its characteristics. It is given by the ratio of the standard deviation to the mean as indicated in the equation (3) [2].

$$C_k = \frac{\sigma_k}{\overline{P}_k} \qquad (3)$$

σ_k : Annual standard deviation; $\overline{P}_k$ annual mean

If the coefficient of variation is less than 1, the distribution will be said homogeneous, and which means that the data will be considered as close to one the other. If the coefficient of variation is greater than 1, the mean is a poor indicator of the central tendency of the raw data; in such a case, it is better to choose the median as a measure of central tendency.

3. Application

This study deals with the Fatick River Basin, notably in its low valley, in Senegal. It is based on rainfall data of four raingauges during a period extending from 1981 to 2016 acquired from the database of ANACIM (National Agency of Civil Aviation and Meteorology). Our procedure is essentially structured in 3 components related to variability analysis based on Standardized anomaly index, precipitation concentration index and coefficient of variation. Our motivation, at that level, is to observe climatic variations the Fatick region had to face during that chronical, to provide information on rainfall variability, to analyze and understand hydrological processes and key elements affecting water availability in this area.

4. Results and discussion

4.1. Standardized anomaly index

Standardized anomaly index for Toubacouta and Ndofane raingauges are depicted respectively in Fig.2a and Fig.2b. Reading the fig.2a highlights15 wet years and 21 dry years and that of fig.2b shows 11 wet years and 25 dry years. Fig.2a shows 2010 as the most surplus year and 1991 as the most deficit year. Fig.2b shows 1999 as the most surplus year and 1994 as the most deficit year. Analysis of fig.2a based on the classification defined in [24], reveals 4 wet years,3 moderately wet year,23 normal year (whose 15 light drought years), 4 moderately dry year and 2 dry years. That of fig.2b allows identifying 2 extremely wet year, 1 wet year ,1 moderately wet year, 29 normal year (whose 22 light drought years) and 1 dry year. These results exhibit certain characteristics of dry years; they demonstrated the intensity and frequency of drought in the studied stations vis-a-vis for the wet years. Indeed, frequency occurrence of below normal rainfall increased over the study period. In this regard, 70% of the years have recorded below long term average at Ndofane station and 59 % in that of Toubacouta . In conclusion, the rainfall pattern in the studied stations shows an increasing trend towards deficit slightly in space while being a little bit persisting in time. It emerges from this analysis that the recurrence of drought that is more pronounced at Ndofane than Toubacouta.

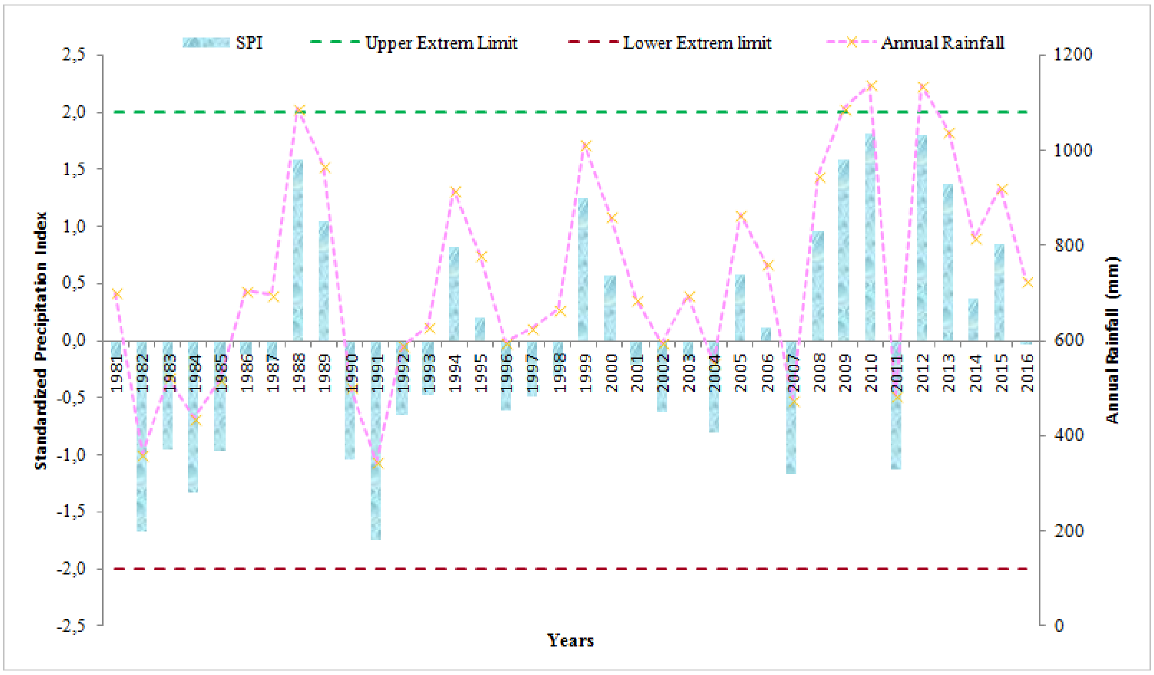

Figure 2a: Standardized precipitation index evolution at Toubacouta raingauge

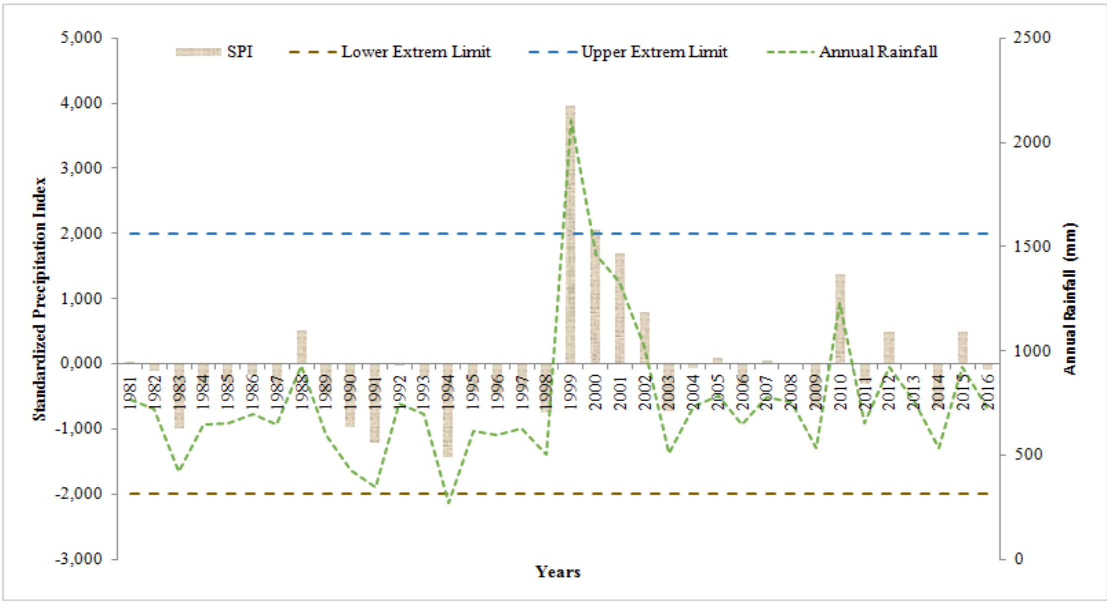

Figure 2b: Standardized precipitation index evolution at Ndofane raingauge

4.2. Precipitation Concentration Index

We present in Fig.3a and Fig.3b Precipitation Concentration Index (PCI) chart for Toubacouta and Ndofane raingauges respectively. Analysis of PCI value revealed that both two stations have greater than 20%. Based on the scale defined in [46], results are grouped under high and very high concentration which indicates poor monthly distribution of the rainfall. Such values correspond to climate with marked monthly contrasts in rain intensity. The highest irregularity was observed in 2007 for Toubacouta raingauge and 1994 for Ndofane raingauge. The lowest irregularity was observed in 1995 for Toubacouta raingauge and 1983 for Ndofane raingauge. The results also indicate, that the total precipitation occurred in 1/3 of the study period (i.e., total annual precipitation occurred in 4 months) . Moreover, PCI values are used to evaluate the rainfall seasonality based on the scale defined in [49] . So, analysis of results on seasonal scale, shows 18 seasonal years (PCI < 30) and 18 highly seasonal years ($30 \leq$ PCI ≤ 40) for Toubacouta; those related to Ndofane station, show 3 irregular distribution years (PCI > 40), 16 seasonal years and 17 highly seasonal years.

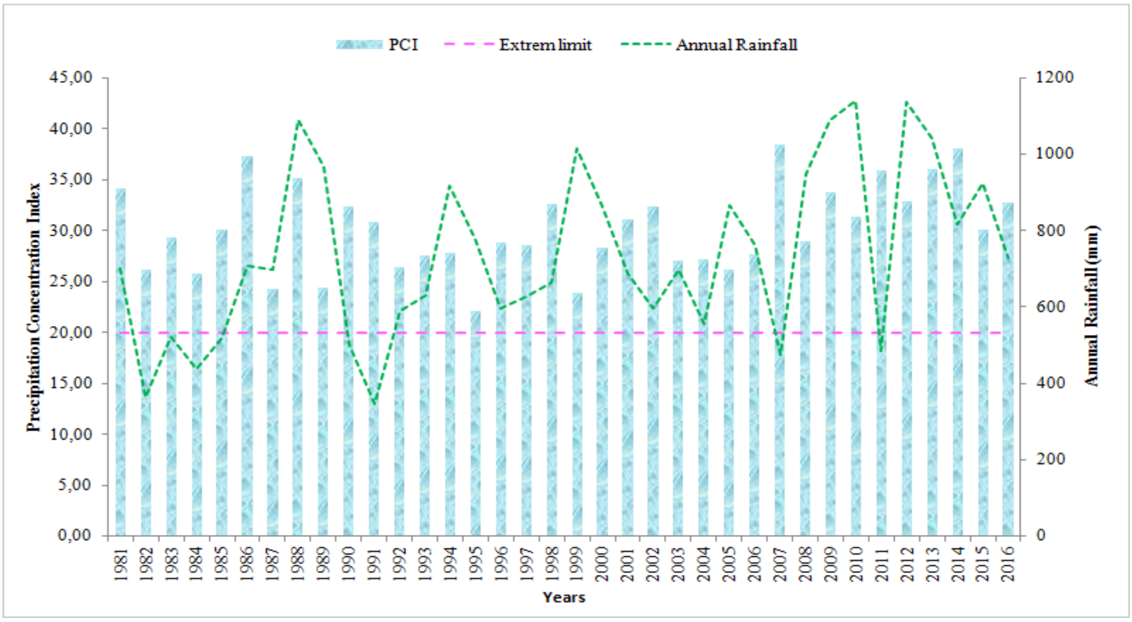

Figure 3a: Precipitation Concentration Index evolution at Toubacouta raingauge

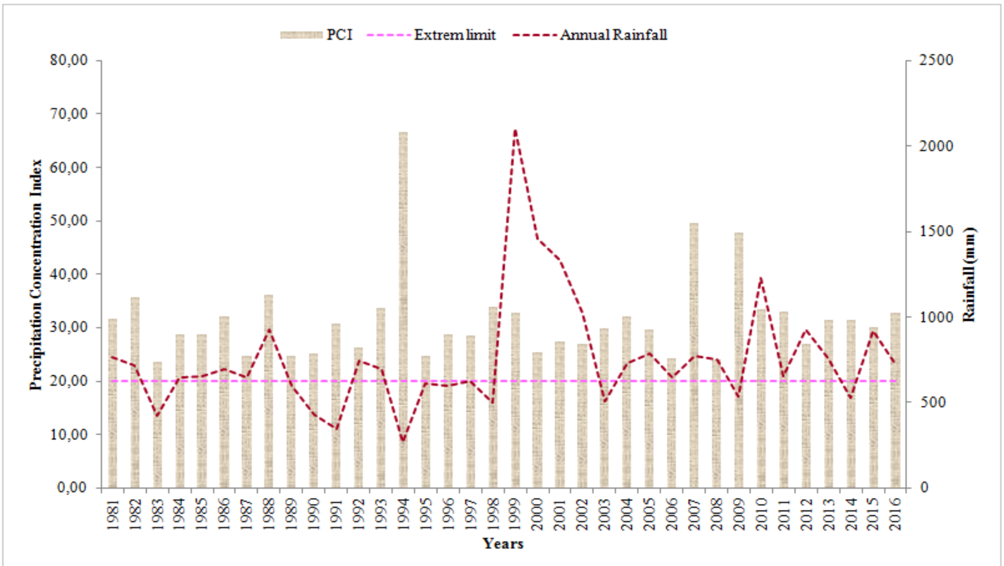

Figure 3b: Precipitation Concentration Index evolution at Ndofane raingauge

4.3. Variation coefficient

Fig.4a and Fig.4b. illustrate the distribution of variation coefficient respectively at Toubacouta and Ndofane raingauges. Reading of fig.2a and fig.2b shows that virtually all the values of the variation coefficient exceed the reference value for both stations, which highlights higher variability of average annual rainfall in the study area.. Figure 2a indicates highly distribution of rainfall over the entire study period (1981 - 2016). For the Fig.2b, highly distribution of rainfall is occurring the period 1981-2001 and 2004-2016.However, for years 2002 and 2003, the distribution is homogeneous. The year 2007 has the highest coefficient of variation value (corresponding to extreme variability) and the year 1995 the smallest (corresponding to extreme homogeneity) for fig2a. The year 1994 has the highest coefficient of variation value (corresponding to extreme variability) and the year 2002 the smallest (corresponding to extreme homogeneity) for fig2b. Comparing the coefficient of variation of the two stations, rainfall is more variable for Toubacouta than Ndofane. In conclusion, we can say that: i) in the case where the coefficient of variation is less than 1, the data is considered as close to one the other; ii) in the case where the coefficient of variation is greater than 1, the mean is a poor indicator of the central tendency of the raw data; in such a case, it is better to choose the median as a measure of central tendency.

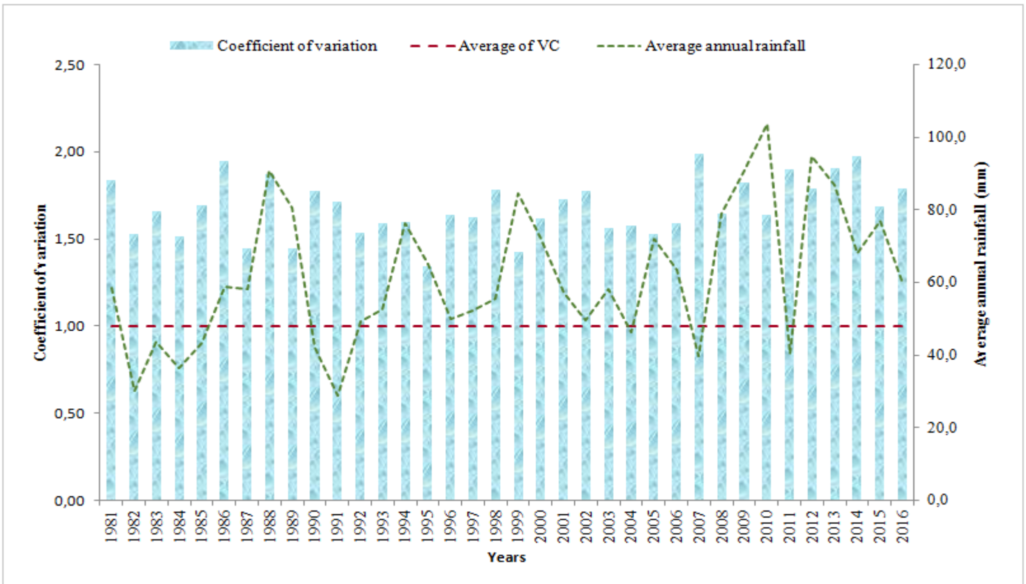

Figure 4a: Variation coefficient evolution at Toubacouta raingauge

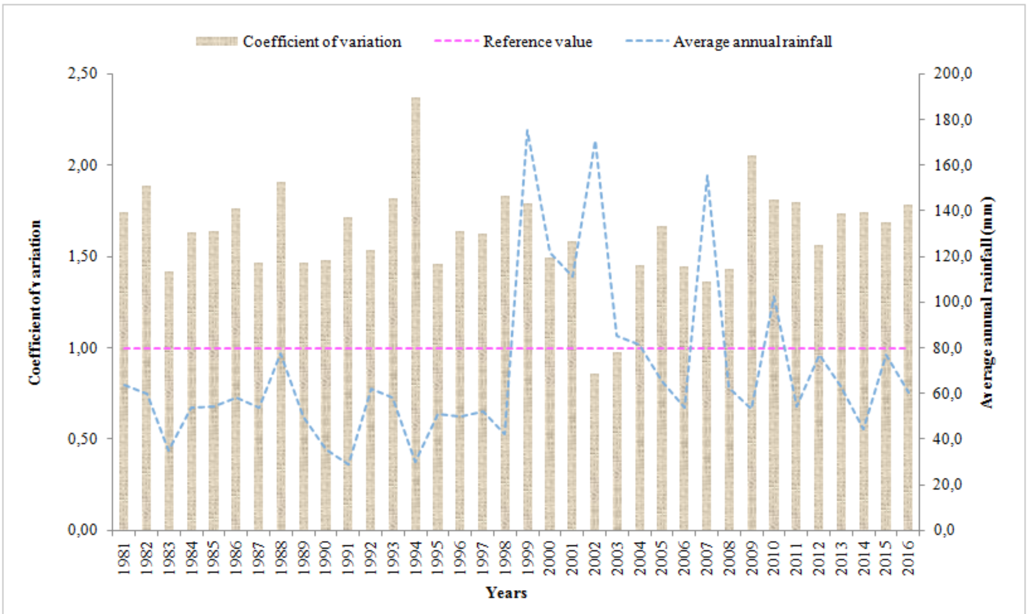

Figure 4b: Variation coefficient evolution at Ndofane raingauge

5. Conclusions

Analysis of precipitation at annual scale is an important step towards understanding of elements affecting water availability. This study mainly focuses on the assessment of changes occurring in the spatial and temporal distribution of rainfall with 36-years database of monthly precipitation for identifying the annual distributions, variations and trends in Fatick watershed, Senegal. Such analysis provides information for any reflection related to the understanding of hydrological processes and key elements affecting water availability in this area. In that respect, we have proceeded through some analysis based on rainfall variability descriptors calculation including standardized anomaly index, precipitation concentration index and coefficient of variation. The slope values obtained from linear regression was calculated to examine the direction of the variability. The results obtained are consistent and speaking. Considering the standardized anomaly index, reading the results highlights15 wet years and 21 dry years for Toubacouta and those of Ndofane shows 11 wet years and 25 dry years. 2010 is wettest year and 1991 the driest for Toubacouta raingauge; for Ndofane 1999 is the most surplus year and 1994 the most deficit year. Moreover, analysis of results based on classification defined in [24],reveals 4 wet years,3 moderately wet year,23 normal year (whose 15 light drought years), 4 moderately dry year and 2 dry years for Toubacouta. That of Ndofane allows identifying 2 extremely wet year, 1 wet year ,1 moderately wet year, 29 normal year (whose 22 light drought years) and 1 dry year. These results exhibit certain characteristics of dry years; they demonstrated the intensity and frequency of drought in the studied stations vis-a-vis for the wet years. Indeed, frequency occurrence of below normal rainfall increased over the study period. In this regard, 70% of the years have recorded below long term average at Ndofane station and 59 % in that of Toubacouta . In conclusion, the rainfall pattern in the studied stations shows an increasing trend towards deficit slightly in space while being a little bit persisting in time. On the whole, the recurrence of drought is more pronounced at Ndofane than Toubacouta. Regarding the Precipitation Concentration Index (PCI), results showed PCI value greater than 20% both for the two stations. So, based on the scale defined in [46], results are grouped under high and very high concentration which indicates poor monthly distribution of the rainfall. Such values correspond to climate with marked monthly contrasts in rain intensity. The highest irregularity was observed in 2007 for Toubacouta raingauge and 1994 for Ndofane raingauge. The lowest irregularity was observed in 1995 for Toubacouta raingauge and 1983 for Ndofane raingauge. Moreover, PCI values are used to evaluate the rainfall seasonality based on the scale defined in [49]. So, analysis of results on seasonal scale, shows 18 seasonal years and 18 highly seasonal years for Toubacouta; those related to Ndofane station, show 3 irregular distribution years, 16 seasonal years and 17 highly seasonal years. It emerges from this analysis that the rainfall regime is changing in Fatick area and irregularity is more pronounced at Ndofane than Toubacouta. For results related to variation coefficient, analysis shows that virtually all the variation coefficient values exceed the reference value for both stations, which highlights higher variability of average annual rainfall in the study area. Thus, those of Toubacouta indicate highly distribution of rainfall over the entire study period (1981 - 2016) For Ndofane, we have highly distribution of rainfall occurring the period 1981-2001 and 2004-2016.However, for years 2002 and 2003, the distribution is homogeneous. The year 2007 has the highest coefficient of variation value (corresponding to extreme variability) and the year 1995 the smallest (corresponding to extreme homogeneity) for Toubacouta. The year 1994 has the highest coefficient of variation value (corresponding to extreme variability) and the year 2002 the smallest (corresponding to extreme homogeneity) for Ndofane. Comparing the coefficient of variation of the two stations, rainfall is more variable for Toubacouta than Ndofane. On the whole, the results obtained are convincing and promising. They allow us to make plosive assumptions about the climatic hazards of this period. Ultimately, rainfall in Fatick has been subject to irregularity and some general tendency to decrease; in fact, the deficit periods are slightly more extended in space and a little bit more persisting in time than the surplus periods. On the whole, the results obtained are convincing and promising. They allow making plosive assumptions about the climatic hazards of this period. Such results provide some very interesting indications for authorities and climate specialists to develop adaptive strategies to mitigate negative impacts climate change and dependency of agriculture to natural rainfall. This would be an undeniable condition to guarantee food security through food system stability. However, to better understand the irregularity of annual precipitation regime, it would be interesting to find a law of adjustment (such as normal Gaussian law) of the distribution of the rains in order to arrive at an estimate of the parameters of adjustment. The application of the chi 2 test will verify the adequacy.

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