Original Research Article

Study of hydrological parameters in Sine Saloum River basin in a context of climate change and variability

ABSTRACT

Drought is one of the most worrying manifestations of variability and change of climate in many West African countries. Due to its threats on human life, socio-economic activities, agricultural productivities, shortage of water, natural resources and environments, the problems related to drought have caught the attention of scientists, researchers and policy makers in recent decades. The aim of this paper is to characterize and analyze climatic events and their impact on water resources, environmental ecosystems and population. For this, we have selected rainfall time series of Sine Saloum river basin at Foundioune's rain gauge. We have first conducted an exploratory analysis based on the graphic study. So, histograms relating to annual rainfall, monthly rainfall decadal, interannual monthly rainfall and interannual monthly averages, were analyzed separately compared to the corresponding average; this has highlighted the spatial and temporal distribution of intra and inter annual rainfall compared to the average and allowing viewing wet and dry years and months. We have secondly calculated the drought indices such as standardized precipitation index and normal precipitation index to evaluate climate fluctuations, characterize the progression of drought and its degree of intensity. This has also highlighted the deficit years and surplus years. In total, the 43 years of the study period, we were 13 wet years including and 30 dry years; 1971 was the wettest years and 2007 less rainy. Characterization of these 30 deficit years has highlighted 3 categories of drought: mild drought, moderate drought and great drought. It appears from this study that the impacts of drought can be attributed in part to a deficit or erratic rainfall. Analysis of the results has showed the high vulnerability of the watershed to drought. Examination of drought years revealed a higher frequency in space and in the time of light drought.

Keywords: Drought, Climatic fluctuations, Water availability, Development projects, developing countries, Sine Saloum Watershed, Senegal.

1. INTRODUCTION

It is increasingly recognized that : 1) appropriate water resources planning and management at a river basin level is viable only by considering the impact of climate change/variability on water resources [1-2] ; 2) many economic and social human activities have disappeared or are threatened to disappear [3-4] ; 3) climatic change is at the origin of several natural disasters on the lives of the population and the environment (flooding, drought, desertification, etc) on a worldwide scale [5-6-7-8] and 4) climatic change resulted in a significant decline in agricultural output (rainfed), an imbalance in the water supply of the population and livestock and a significant decrease in the response of watersheds especially in developing countries [9-10-11-12].This awareness made that investigations of regional and global climatic changes and variabilities and their impacts on the society have received considerable attention in recent years[13-14]. The most adapted variables for monitoring climate manifestations are: the flow of the rivers, lake levels the rainfall, the temperature and the level of groundwater etc [15]. Among these variables, precipitation represent the most important climate factors for both population and for ecosystems and they are the most accessible measures in various parts of the world [16-17] . In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades [14]. Much attention had been paid to analyze climatic changes in these regions of world [18-19-20] **:** [21] studied the impact of climate change on water resources of the Hanjiang basin and their results showed that the precipitation change is the main factor for the change in runoff ; [22] used precipitation, temperature and runoff data to analyze and assess the impact of climatic change on the water resources in China ; [23] have investigated the impact of climate change on monsoon in Tamil nadu ,India and they have identified shift in rainy season over the period from 1950 to 2010 and pre-monsoon sowing weeks at block level. Many studies on climate variability in West Africa have shown rainfall anomalies that have affected the flows of rivers, causing a considerable drop in their hydrological characteristics, degradation of vegetation cover (which has an influence on hydrological regimes) and many socio-economic problems whose effects are often difficult to reabsorb [24-25-26] **:** ([27-28-29] showed that a drying trend was evident from the end of the 1960s confronting Ivory Coast to the water problem including a drying up of most surface water sources, many wells and therefore a significant drop in groundwater level tablecloths; [30] examined the impact of climate change on the evolution of N'zi River (main river of the Ivory Coast) ; [31-32-33] showed that beyond immediate response annual flow of rivers to deficit rainfall season, some sustainability deficit hydrological should be attributed to the cumulative effect of years of drought. Other studies have been conducted by various researchers to assess the impact of climate variability on water resources and population dynamics : [34] evaluated the impact of declining rainfall on aquifers in the region of Odienné ; [35] conducted a comparative study of the effect of drought on the watershed and that of N'zi N'zo ; [36] studied the relationship between climate variability and human activities ; [37] analyzes the interannual variability of rainfall and flows to assess the water availability in the basin of the Lobo in Ivory Coast ; [38] studied the existence of climate variability in Côte d'Ivoire, specifically in the area of Abidjan-Agboville, and its impact on water resources supply. In Senegal, like the study of the interannual variability of rainfall ; [39] showed alternating wet and dry periods period ; [40] characterize the effect of climate variability and human actions (dams) on his regime and, subsequently, to shed light on the recent evolution of flows in the watershed River Senegal ; [41] analyzed the spatial and temporal variability of rainfall across the Senegal River basin from the top-ten of the data reference stations; they showed that southern basin has the largest surpluses during periods of surplus, but also the highest deficits in deficit periods ; [42] highlight the effect of climate change in the Gambia River Basin and its impacts on the availability of the water resources of this basin by using its runoff and rainfall time series. These various studies show that the African continent has an increased risk of vulnerability to perturbations induced by climate change. Unfortunately, the continent's capacities for adaptation, remain weak mainly dune causes lack of hydro observational data. Given the increased vulnerability of sectors such as agriculture, food security, water supply and ecosystems, it is important to take into account and, if necessary, adjust the concepts of sustainable development and strategies Development [43]. This has placed Africa at the heart of the scientific debate on the search for a better understanding of climate and these interactions [44]. It is for these experts, to collect evidence and information related to climate change, analyze and characterize their impact on key areas of human and ecological development. Furthermore, analysis and precise characterization of climate events, and its relationship with the variability of water resources requires data quality and methodological rigor in order to establish a relevant diagnosis and develop adaptive strategies operating in the sense that they must lead to the development scenarios for forecasting and sustainable water resources management [45-46-47]. In this paper, we focus on the Sine Saloum River basin in Senegal. The aim of this study is to characterize and analyze climatic events and their impact on water resources, environmental ecosystems and population through rainfall time series analyses. Possible changes in these climate variables can be reduced to two types of changes to be analyzed: the change of the mean and the variance. The methods used to reach this objective, are described in flowing section. They were developed by meteorologists and climatologists and are used all over the world for surveillance or monitoring of drought. Our main motivation through this article is to equip decision makers to allow them to adapt their natural resource management strategies (forests, water, agriculture) to the problems of climate change and to strengthen the scientific basis for reflection.

2. MATERIAL AND METHODS

2.1 Study Area and Data

The Sine Saloum (Figure 1) is a delta formed by the confluence of two rivers, the Sine and Saloum [48]. The natural region of Sine Saloum (180,000 ha), is limited to the south by the Republic of The Gambia to the north by the River Saloum and on the west by the Atlantic Ocean between latitude 14 ° 11 'N and longitude 16 15 'W. Its watershed drains an area of 2 959 km^2 to Foundioune station [49]. The climate is Sudano-Sahelian and is characterized by two seasons determined by the movement of tropical air masses: i) the rainy season: from June to October, during which the area is covered by monsoon and hot wind wet precipitation generator coming from the St. Helena anticyclone and ii) the dry season (November to May), during which the maritime trade wind blows, no precipitation damp wind generator, from the Azores and Harmattan, dry wind coming from the anticyclonic cell Maghrebian [48]. Average annual rainfall is estimated at 700 mm Foundioune station. The lowest temperatures recorded from July to February, generally vary between 19 and 30 ° C; the high temperatures recorded from March to June with both reaching from 39 ° C. The average is often estimated 27 ° C [50]. The natural region of Sine Saloum has three rainfall stations. After a laborious selection based on the quality and length of the series of available recordings, the data Foundioune station, are retained. Thus, this series composed of the monthly and annual rainfall data, were studied. They are acquired from the database of ANACIM (National Agency of Civil Aviation and Meteorology) that guarantees its quality and reliability. The periods extending from 1970 to 2012 has been selected.

Fig.1.Sine Saloum River basin at Foundioune station

2.2 Exploratory Analysis

The exploratory analysis is a technique to highlight certain factors explaining the correlation and dependency between some of our variables. It starts data and is based on a logical observation to get an overview of the data and discover forms of regularity. This method consists of a graphical representation of all observations to visually see how they evolve during the period. For this article, we studied the annual and interannual variability of rainfall to visually observe the evolution. In order to assess the evolution of rainfall in terms of deficit or surplus in the different years of the study period, we evaluated the rainfall index and the rainfall index. These drought indices are chosen for their ease of use and effectiveness in terms of monitoring the progression of drought and assessment of climate fluctuations. Generally, we speak of deficit year (dry) when the rain is below average and over-year (wet) when the average is exceeded [51-52-53]

2.3 Standardized precipitation index (SPI)

This index is used to examine an interannual variability of rainfall and the nature of the trends [30-40-54]. This index is a simple, powerful and flexible both based on rainfall data and allows as well to check the periods / wet cycles that periods / dry cycles. This index compares the rainfall over a period to the long term average of observed rainfall on the same site. It has the advantage to be able to determine the water deficit throughout the season and throughout the year [55-56]. Its formula is given:

$$u_i = \frac{X_i - \overline{X}}{\sigma}$$

Where: $\overline{X}$: the average rainfall for the same time period studied; σ : the standard deviation, X_i : the precipitation of the year and i.
According to [51-56], SPI values intervals to identify anomalies in rainfall are following:

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

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

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

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

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

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

If $u_i < -2$: extremely dry year

In general, a positive value of this index indicates a rainfall surplus and a negative value a deficit.

2.4 Normal precipitation Index (NPI)

The Normal precipitation Index is used in the analysis of the interannual variability of rainfall. It can also highlight the alternation of wet and dry periods. It is given by the formula [52] :

$$I_P = \frac{X_i}{\overline{X}}$$

X_i is the precipitation of the year and i , $\overline{X}$ is the average rainfall for the same time period studied.

This report makes a point estimate rainfall compared to normal. According to [56-57], one year is classified as dry or wet in the record:

If $I_P > 1$: wet year;

If $I_P < 1$: dry year.

We made the analysis of the evolution of these two indices rain founded a graphical method.

3. RESULTS AND DISCUSSION

3.1 Results on the exploratory analysis

3.1.1 Annual Rainfall

We present in Figure 2 the evolution of annual precipitation for Foundioune station. The analysis based on the comparison between the annual rainfall and the annual average, allowed to visualize and determine the number of deficit and surplus years and their succession. So, on the 43 years of the study period, we have counted 13 deficit years (30%) and 30 surplus years (70%). It can be remarked that 1971 was the wettest year and 2007 is the least rainy year.

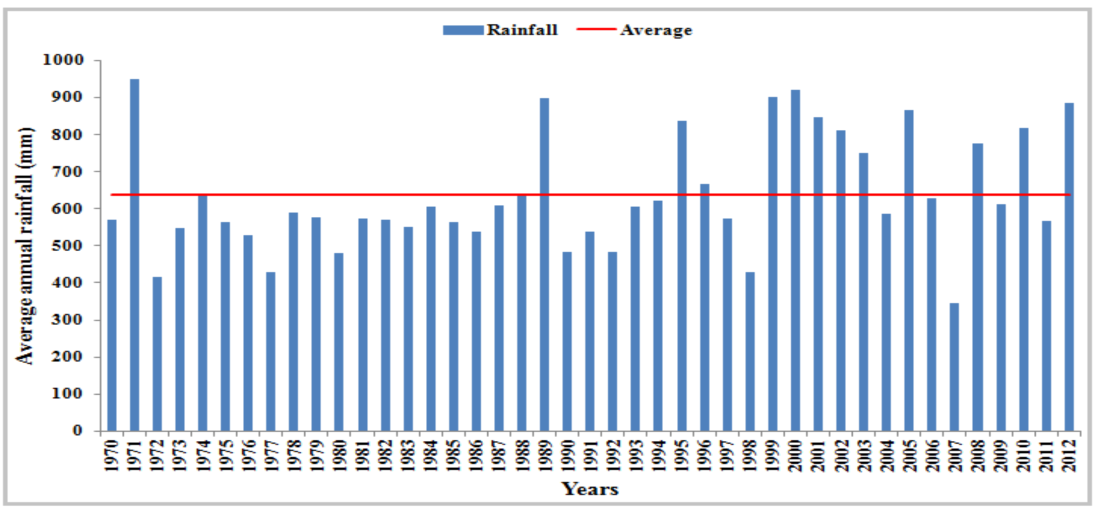

Fig. 2. Evolution of annual rainfall over the period 1970 to 2012

3.1.2 Monthly rainfall decadal

Figure 3 shows the evolution of monthly rainfall decadal averages of the different decades of the period 1970-2012. We focused in this part of the 5 month rainy in the region (June, July, August, September and October). Analysis of the monthly rainfall for 10 year interval showed that the decade from 1992 to 2002 (Figure 6c) is the wettest 3 months on average about 5 rainy months of each year of this period, recorded rainfall above average. The decade 1970-1990 (Figure 6a) appears as deficit period: 3 months on five rainy months have a lower than average rainfall. The last decade (Figure6e) is more humid than the decade (Figure 6b); resulting in a heterogeneous distribution of rainfall intensities on the whole basin. Furthermore, analysis of rainy months for each year of different decades reveals that the month of June is the driest and the month of August is the wettest. These results show that rainfall variability is manifested by a significant change in the monthly rainfall.

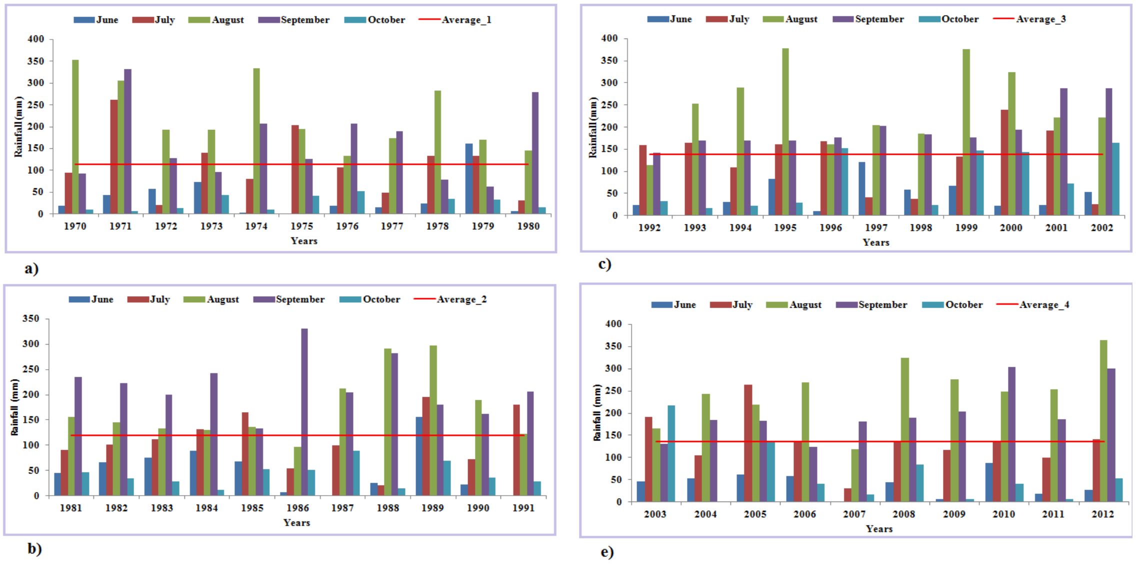

Fig. 3. Evolution of the monthly rainfall decadal over the period 1970 to 2012.
a) decade (1970-1980); b) decade (1981- 1991); c) decade (1992-2002);
e) decade (2003-2012)

<u>3.1.3 Interannual monthly rainfall</u>

We present in figure 4 the evolution of interannual monthly rainfall. Analysis of the results shows that: the rain height of June varies from 0 to 160.5 mm, i.e. a gap of 160.5mm (Figure 4a); the height of July varies from 20.2 to 264.7mm, i.e. 244.5 mm (Figure 4b); the height of august varies from 96.6 to 378.7, i.e. a gap of 282.1 mm (Figure 4c) ; height of september varies from 63 to 332.1 mm, i.e. a gap of 269.1 mm (Figure 4d) and the height of october varies from 0 to 217.8 mm, i.e. a gap of 278.8 mm (Figure 4). In definitive, the month of August which has the largest gap, emerged as the rainiest months and June and having the smallest gap, is the least rainy.

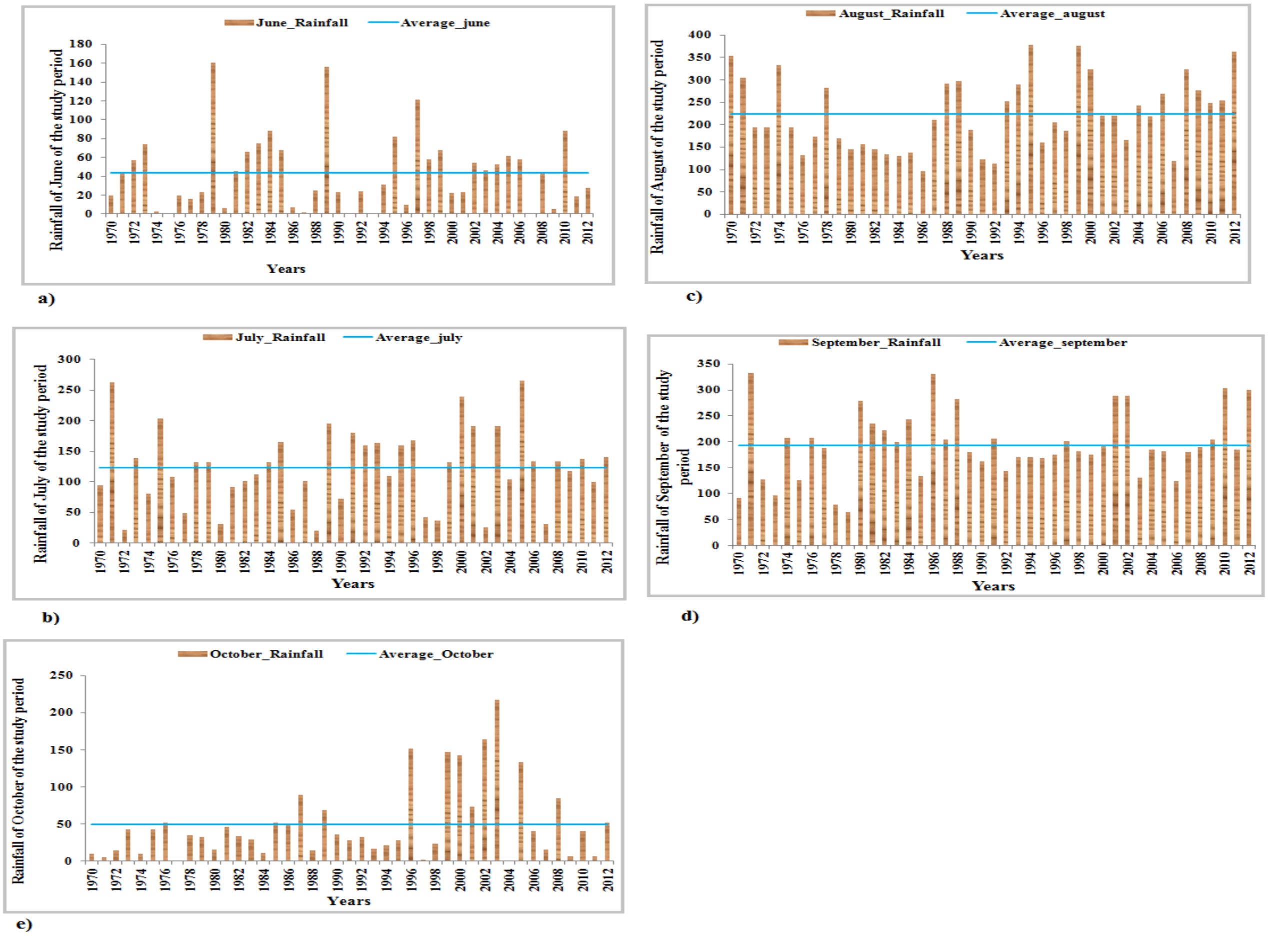

Fig. 4. Evolution of interannual monthly rainfall over the period 1970 to 2012
a) June; b) July; c) August; d) September; e) October

3.1.4 Interannual monthly rainfall averages

Figure 5 illustrates the evolution of interannual monthly averages of the study period. The analysis is done with respect to the reference. It reveals two surplus months (August and September) and 3 deficit months (October, July and June). The month of August is the wettest and June the least rainy months. These observations are similar to those of Figure 4. They also corroborate with those made earlier on rainfall deficits.

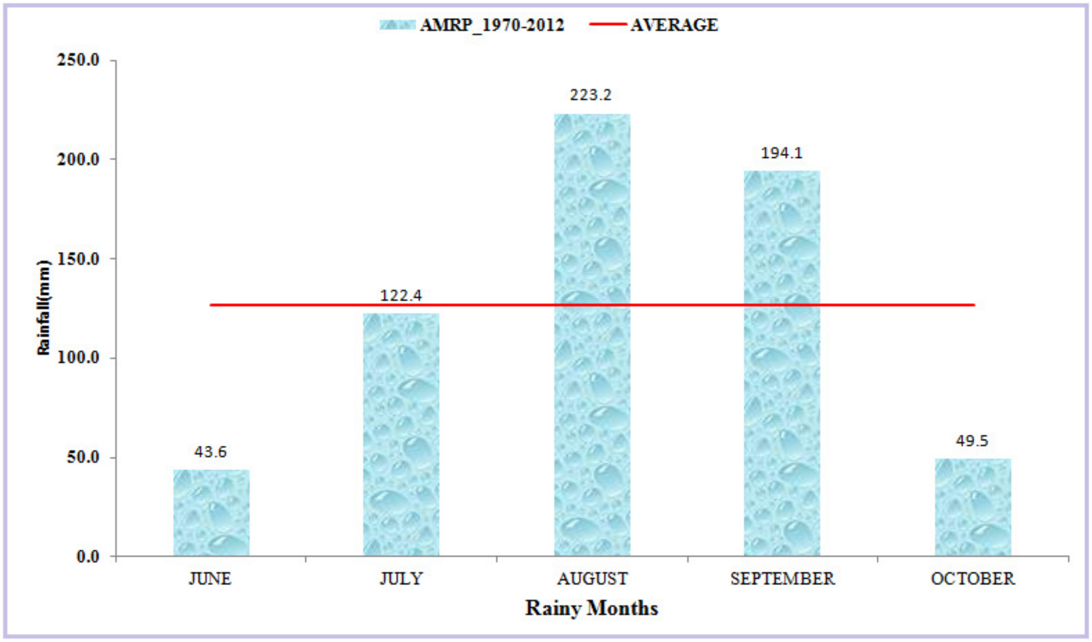

Fig.5. Evolution of the interannual monthly rainfall averages over the period 1970 to 2012.

3.2 Results on drought indices

3.2.1 Standardized precipitation index

We present in figure 6a the evolution of the standardized precipitation index (SPI) to evaluate the variations of annual rainfall (dry or wet years) and Figure 6b to characterize the level of drought severity. Thus, a year is qualified wet if the index is positive and dry when it is negative. The analysis of Figure 6a shows dry years (in blue) and wet years (in orange). There are a total of 13 wet years and 30 dry years; this confirms the recurrence of drought. The 1971 is the most deficit year and 2007 the most surplus year. The analysis of Figure 6b allowed according to [51] classification, to characterize drought in 3 categories: light drought $(-0.99 < u_i < 0)$; moderate drought $(-1.49 < u_i < -1)$ and great drought $(-1.99 < u_i < -1.5)$. Of the 30 dry years, we have identified 24 times the light drought (a frequency of 80%), 5 times the moderate drought (a frequency of 16.7%) and 1 times the great drought (a frequency of 3.3%). These results show that the deficit periods are extended in space and more persistent in time than the surplus periods.

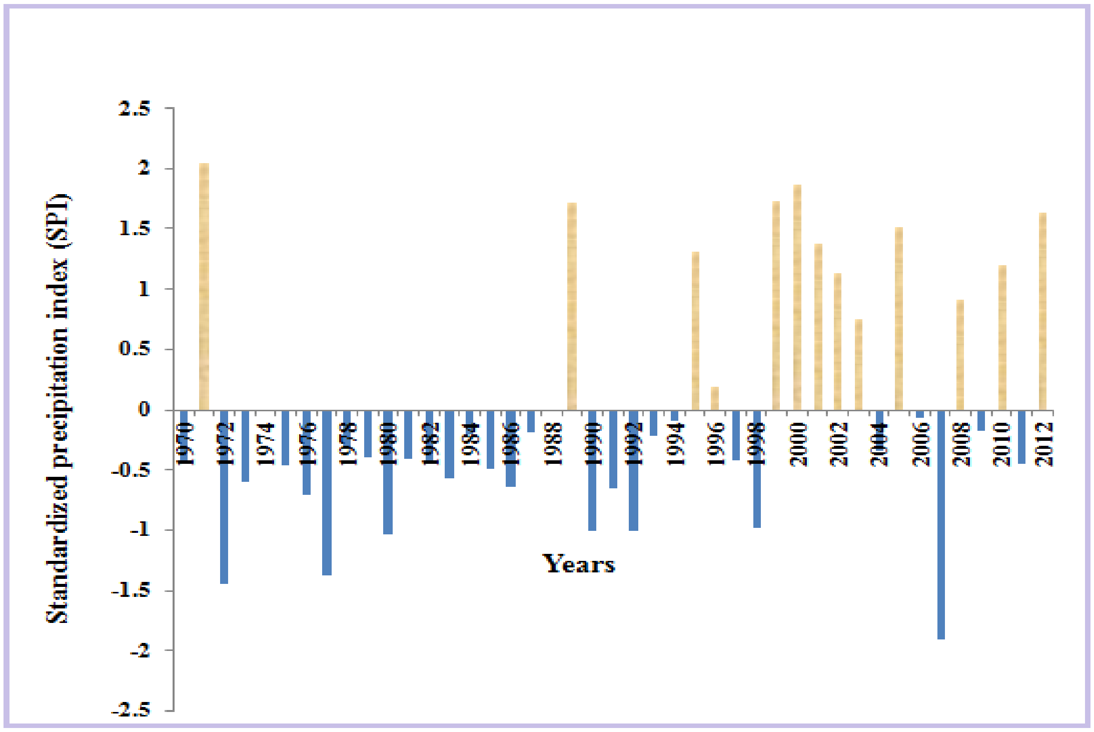

Fig.6a. Evolution of the standardized precipitation index (SPI)

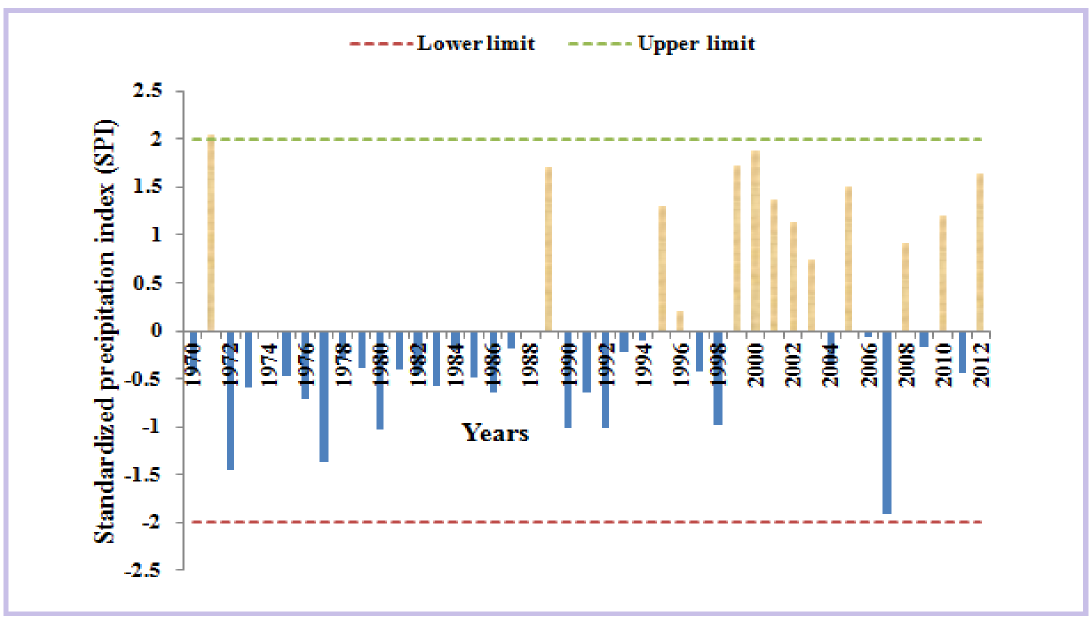

Fig. 6b. Evolution of the standardized precipitation index (SPI) with the limits

3.2.2 Normal precipitation Index (NPI)

We present in figure 7 the evolution of normal precipitation index to highlight the dry and humid sequences, those of them that are very deficit and very surplus. The analysis of this figure shows 13 wet years and 30 dry years. Among the dry years ,2007 which has a value of (NPI) very inferior to the reference, is the most deficit year and among the wet years, 1971 is the most surplus year (NPI value is very superior to the reference). These results are similar to those obtained previously. In definitive, the general trend is a decrease in rainfall in the study area. The inter-annual variability increased with brutal alternation between very wet and very dry years. This fact will make it even more difficulties inter annual forecast of rain in Senegal in general.

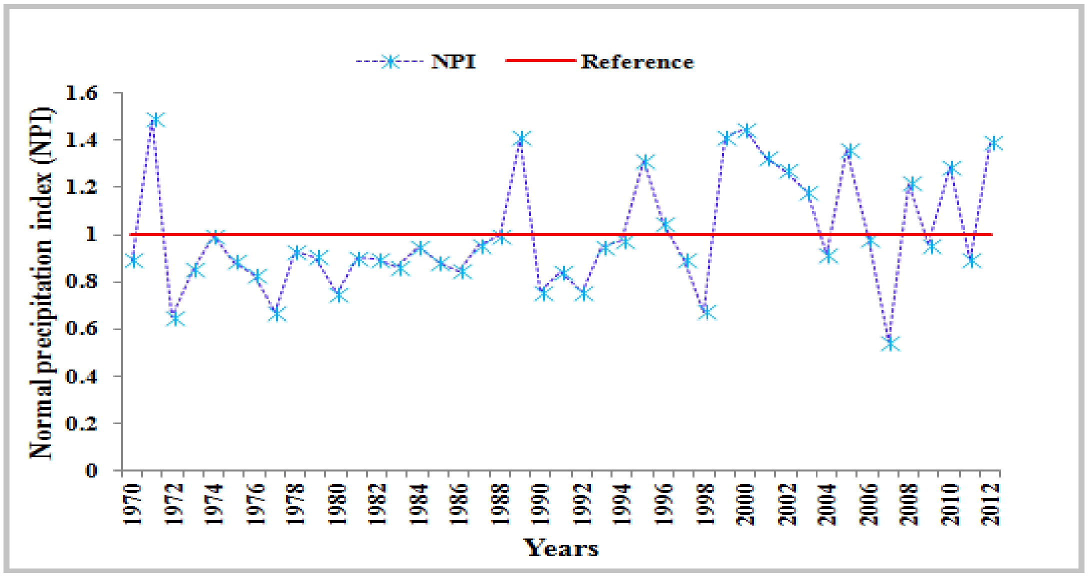

Fig. 7. Evolution of the normal precipitation index (NPI)

4. CONCLUSION

Drought is a disaster that results from a decrease in rainfall compared to levels considered normal. When it is persistent, rainfall is insufficient to meet the needs of the environment and human activities. Drought is a regional phenomenon and each region has its own climate characteristics. Therefore supervision or monitoring uses many different methods. In this study, we used an exploratory method and a method based on calculation of drought indices recognized by meteorologists and climatologists worldwide. We focused on the watershed of the sine Saloum (Senegal), we have selected the monthly and annual rainfall data at Foundioune raingauge and rainfall from the ANACIM (National Agency of Civil Aviation and Meteorology) that guarantees quality and reliability. Thus, to appreciate the evolution of monthly and annual precipitation and dispersion of values compared to the mean, histograms on annual rainfall, monthly rainfall decadal, interannual monthly rainfall interannual monthly rainfall averages were analyzed. The analysis of the results allowed: to view 13 wet years (13) and 30 dry years; to remark that 1971 is the wettest year and 2007 is the least rainy; to identify that (1992-2002) is the wettest decade and (1970-1990) is the driest decade and to find that August is the rainiest months and June is the least rainy month. To confirm this temporal and spatial rainfall variability and to assess the degree of drought, we used standardized precipitation index and the normal precipitation index. Analysis of the results also showed 13 surplus years and 30 deficit years. The characterization of the severity level of drought through these 30 dries years, made appear:

light drought (80%), moderate drought (16.7%) and great drought (3.3%). According to these results, we can remember that Sine Saloum River basin, is vulnerable to drought, the occurrence of more or less long dry spells is a dominant characteristics of the resource regime. These conclusions are very interesting for the study of climate in the country and the sub region. They can reinforce the capacity of the countries to ensure monitoring of meteorological droughts and evaluate it, assess the impact of rainfall variability in the volume of water passed, trace the trends of major fluctuations in rainfall and hydrometric regime. This study must however be complemented by an analysis of changes in flow regime and the use of the remote sensing for the reliable monitoring and planning of drought in regional scale.

5. RECOMMENDATION

Climate change is a reality around the world. It constitutes a serious threat on economic and environmental development strategies, on energy security, on efforts to fight against poverty, hunger and insecurity. To enable better conditions of life and existence, the need for better adaptation has never been so obvious and timely. The extent of the damage must lead to a collective and participatory intervention in the neediest areas. This must move towards a globalization of analysis and observation methods in each region and possibly every locality in the world in order to establish a relevant diagnosis and to design strategies and adaptive operating. The African continent which is unfortunately and sadly most vulnerable, must unconditionally recognize the benefits of a strong and rapid response against the change. It must demonstrate innovative and intelligent governance mechanisms and political will that define the act. Africa must make this battle his to hope to reach at least, food self-sufficiency which it has long dreamed otherwise it will forever become beggar or simply a continent endangered.

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