Drought analysis using the Regional Drought Identification Module: a Case study of Selibaby in Southern Mauritania

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ABSTRACT

The present report summarizes the results of Regional Drought Identification Module for drought identification and characterization through the theory of runs, and the Standardized Precipitation Index (SPI) which is the most used application in Sahelian context. Precipitation is the only hydrological variable used here for the quantitative assessment of drought events. The two methodologies were applied at the local scale using monthly precipitation data for the period of 1950-2007 from several weather stations in the region, in12-month time scales. The new tests for randomness and stationarity in rainfall series were also performed for trend detection in a such variable. The pilot study is based on the station of Selibaby representing the region of Selibaby which is located in the southern part of Mauritania and has been chosen as its agricultural interest of the region and as it provides more reliable rainfall data. In this region results indicate 10 drought events, 382 mm of average drought cumulated deficit, 124 mm/year of average drought intensity and 48 % of deficit year over the total number of years. Precipitation anomalies computed by the software indicate that the area of interest has been significantly affected by droughts.

Key words: Drought, Precipitation, Standardized Precipitation Index, Selibaby

1. INTRODUCTION

Drought identification and characterization at the site and regional scale is an important tool for planning and management of water systems as it provides helpful information for the assessment of water shortage risk and for implementing appropriate mitigation measures. For example, drought analysis performed on a streamflow series provides important insights on the water availability, as well as on the expected length and severity of water deficit periods (Antonino et al., 2005).

Several questions relative to drought definition have been reviewed, among others, by Wilhite and Glantz (1987) and Tate and Gustard (2000), showing that the definitions of droughts are particularly related to the human activities and the ecological environments and to the temporal and spatial scale of analysis.

This study test has been carried out using the new version of the software **Regional Drought Identification Module** (REDIM), developed by University of Catania within the framework of the INCO-DC Project "DSS-DROUGHT" (Rossi et al., 2003) and it is absolutely based on precipitation time series data. The main goal of the study is to perform an in-depth analysis of hydrological droughts in Guidimakha region that could be further useful to water resources management services and institutions which are dealing with the negative impacts of climate variability on water and agricultural fields. Methods used here includes new tests for randomness and stationarity in hydrological series, and the drought analysis through the Run methods and Standardize Precipitation Index.

2. Drought identification and characterization

2.1. Data

The subject of this study concerns the region Guidimakha, in the southern part of Mauritania at the edge of the Senegal River.

between 14,5°; 16° of latitude north and 11,5°; 12,75° of longitude west, represented in Figure 1. The region has an area of 10.300 km^2 and is characterised by combined rainfed and after flood agriculture where mainly cereals (wheat and corn) are cultivated, and natural pastures. Despite the proximity of Senegal river which made the water enough abundant for that purpose, the irrigated crops are not importantly spread because of the lack of irrigation policy in the country level.

In order to perform the analysis using the ReDIM software, only monthly precipitation series are required. The rainfall data were acquired from the National Office of Meteorology of Mauritania. The following tables show rainfall stations used.

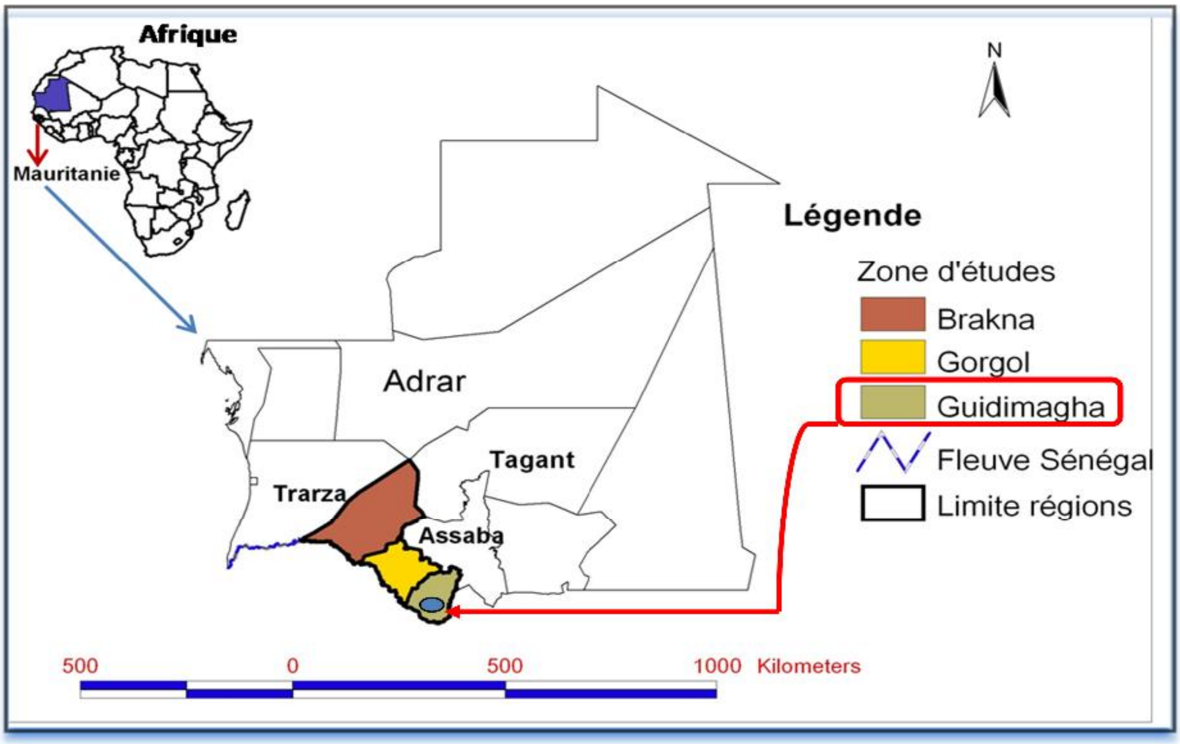

Figure 1: Map of the study area

The site of Selibaby taken as the study pilot is located in Guidimakha region which is the area that receives the highest amount of rainfall in Mauritania (see table 2). The average in the region is about in 540 mm based on the rainfall time series covering the period from 1951 to 2007.

One year of two that means (sample quantile 50%, the rainfall is about 556 mm while the standard deviation for the same sample of rainfall date is about 150

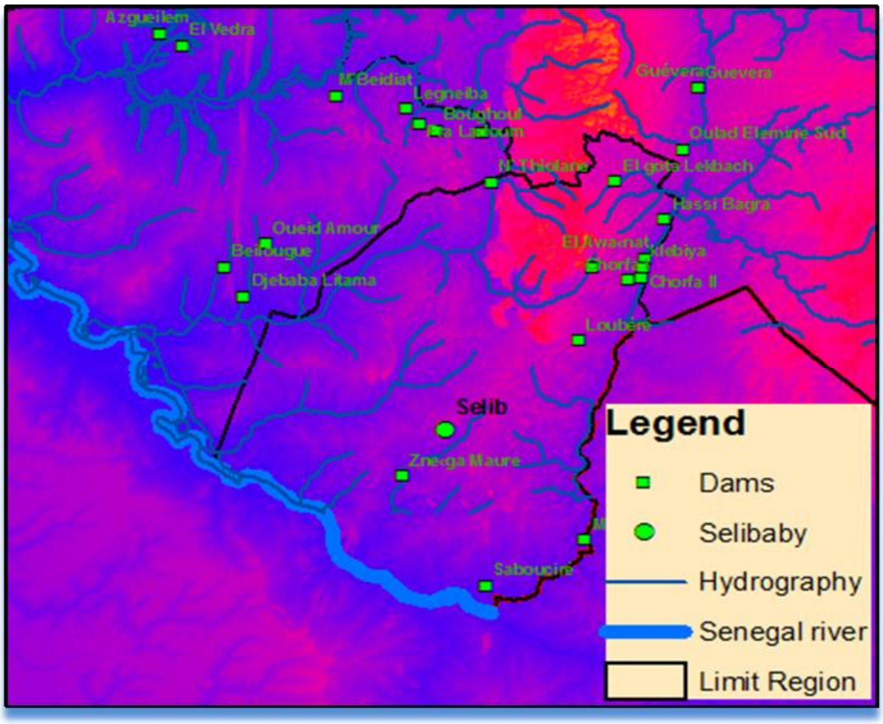

Table 1: Geographical and hydrological Characteristics of the Selibaby rainfall station

Station name	LONG	LAT	Hydrological variable	Threshold (average)	Aggregation time scale	Initial month	Time-series duration
Sélibaby	- 12.17	15.23	Precipitation (mm)	540 mm	Year	January	1950 to 2007

Figure 2 presents the mean monthly distribution of Selibaby precipitation. Rainfall is mostly abundant during the August-September the best period for rainfed crops depending on the conditions of rainfall distribution while it is .

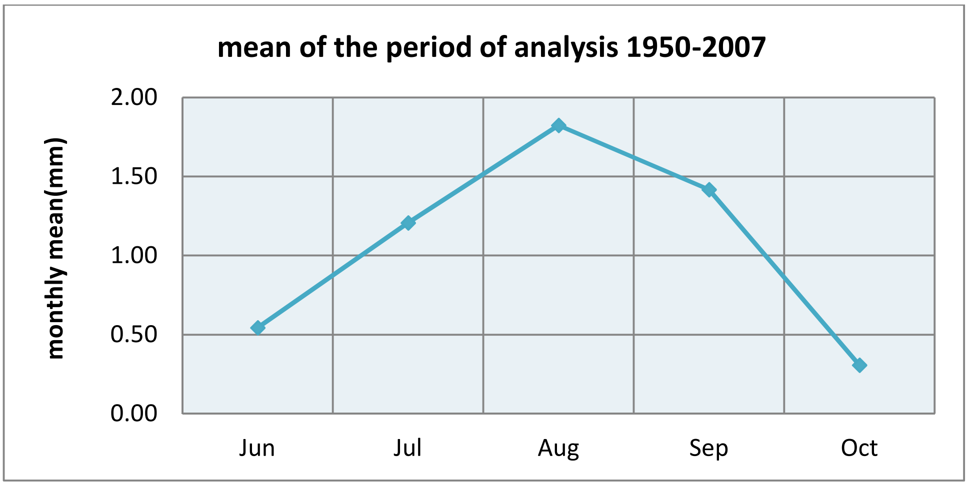

Figure 2: Monthly mean precipitation in Selibaby

Table 2: Geographical and hydrological Characteristics of main rainfall stations from 1950 to 2007

Station	Longitude	Latitude	average Rainfall (mm)	standard deviation (mm)
Selibaby	15.23	- 12.17	539,23	159,70
Boghe	16.57	-14.28	259,63	93,09
Kaédi	16.15	-13.50	290,13	75,55
Aleg	17.05	-13.92	233,88	100,13

2.2. Drought identification at site scale

Information within drought characteristic, for example by deriving the relationship between a fixed value of the drought index and the percentage of the area of the region interested by the chosen value (Rossi, 1980), or by computing regional drought characteristics expressing areal coverage and areal weighted deficit as in the extended run method (Yevjevich, 1967, Tase, 1976)

Among the several indices proposed for describing droughts, a few have found generalised application. One of the simplest drought indices is the percent of normal precipitation related to a month, a season or a year. It is computed by dividing the actual precipitation by the long-term mean (typically 30-40 years), and expressing it as a percentage. Such an index has been computed by Italian Hydrographic Service since its foundation (1919), publishing the isolines of the precipitation for current year expressed as a percentage of the mean of previous values.

The SPI index is based on the consideration that each component of water resources systems react to a deficit in precipitation over different time scales (McKee et al., 1993).

Palmer Drought Severity Index (PDSI) or its slightly modified version (Palmer Hydrological Drought Index or PHDI) are very popular indices in the United States for description of time and space variability of drought events, particularly oriented to drought monitoring and agricultural planning. They are based on a monthly water balance considering a simple two-layer soil and express moisture conditions in a standardized form on a scale ranging from -6 to 6. Droughts are then classified according to the value taken by the index.

The above methods, despite their usefulness for drought monitoring, are not well suited when the purpose is to identify and characterise historical droughts either at a site or at a regional scale. These tasks however are of primary interest when an assessment of drought impacts is needed, especially in order to select best mitigation alternatives. The run method on the other hand allows an objective at site and regional drought identification and characterisation and therefore it represents an ideal candidate methodology for an analysis oriented to define best drought mitigation alternatives.

2.2.1. Preliminary analysis of hydrological time series

Since the method of run is based on the differences between the observed hydrological variable and a constant (or periodic) threshold, it follows that results can be affected adversely by the presence of non-stationarities in the series, such as trends. Consequently, a correct analysis must be preceded by testing the series for the presence of trends, for randomness, and for changes on the mean and the variance. Here, six tests have been considered, namely the t-Student test for linear trends, the Kendall τ-test and the turning point test for randomness, the Rank sum test, the F-test and t-test for the detection of change in the variance and mean respectively.

2.2.2. Concept of Runs

A run is a succession of the same kind of observations preceded and succeeded by one or more observations of different kind. The theory of runs is based on the choice of a critical level, yc. Considering a discrete time series, x1, x2, …,xt …, xn, a negative run occurs when xt is less than yc consecutively, during one or more time intervals. Negative runs in rainfall time series are related to drought characteristics and the difference between yc and xt is referred as deficit.

Given a discrete time series h (i), i=1, 2,… n and a truncation level ho, it is possible to identify positive and negative deviations according to the sign of the difference between the observed values of the variable and the fixed threshold.

By analyzing a given drought *s*, it is possible to identify the following characteristics:

- drought duration *L*(*s*), defined as the number of consecutive intervals where the variable remains below the threshold;
- accumulated deficit *D*(*s*), defined as the sum of the negative deviations, extended to the whole drought duration;
- drought intensity of *ID*(*s*), defined as the ratio between cumulated deficit and duration.

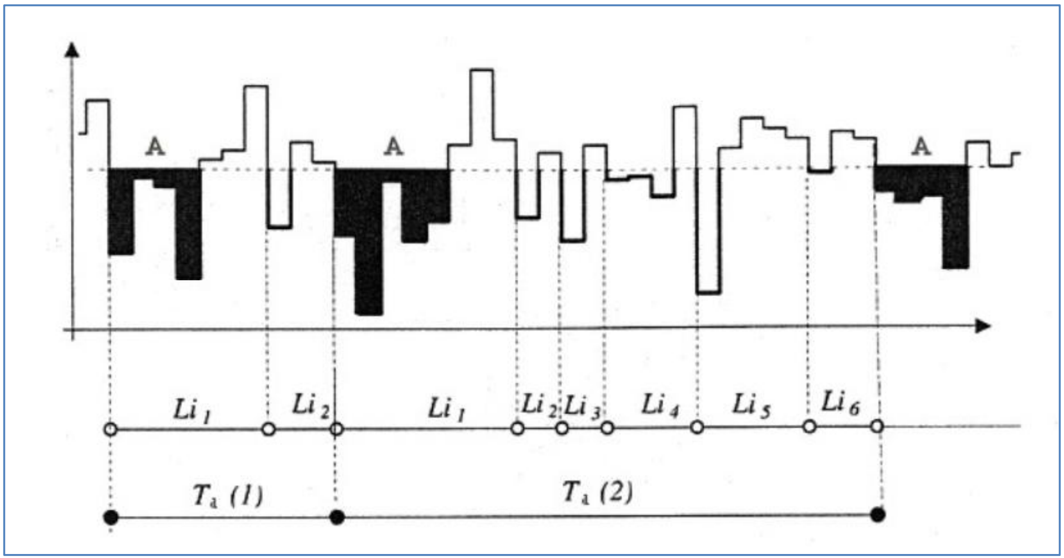

Figure 3: Characteristics of drought events

2.2.3. SPI Method

The Standardized Precipitation Index is a tool developed by McKee et al. (1993) for the purpose of defining and monitoring local droughts. It was conceived to identify drought periods and the severity of droughts, at multiple time scales. Shorter or longer time scales may reflect lags in the response of different water resources to precipitation anomalies. McKee et al. (1993) defined the criteria for a "drought event" for any of the time scales. A drought event occurs any time the SPI is continuously negative and reaches intensity where the SPI is -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The cumulated magnitude of a drought can be considered the drought magnitude, being defined by the positive sum of the SPI for all the months within a drought event. Among the several proposed indices for drought monitoring at site scale, the *Standardized Precipitation Index* (SPI) is far more the most appropriate and useful application in the context of Sahelian regions, here in our case the threshold used for computing the drought classification is both SPI<-1 and SPI=0 using the formula of e de Nicholson $SPI = \frac{P_i - Pm}{std}$ where : SPI represent the Standardized Precipitation Index, Pi the observed precipitation for the year i, Pm the mean precipitation of sample and st.d the standard deviation of the sample.

The main advantages of the SPI are:

- its standardized nature, which makes it particularly suited to compare drought conditions among different time periods and regions with different climatic conditions;
- the possibility to consider different aggregation time scale for drought analysis, which allows to take into account all the possible drought impacts and the related affected

components of the hydrological cycle.

The aggregation time scale should be properly selected according to the aim of the study: i.e., from few months for studies oriented to analyse agricultural droughts (as the soil water content is affected by reduction in precipitation on a short time period), till one year or more for hydrological droughts (since streamflow, ground water, and water volumes stored in the reservoirs are mainly affected by precipitation anomalies over a long time scale).

The following table summarizes the drought classification based on SPI values adopted by the US National Drought Mitigation Center (NDMC, http://www.ndmc.unl.edu).

Table 1: Drought classification according to the National Drought Mitigation Center

SPI			Class
	-	2.00	Extremely wet
from 1.50	to	1.99	Very wet
from 1.00	to	1.49	Moderately wet
from -0.99	to	0.99	Near normal
from -1.00	to	-1.49	Moderately dry
from -1.50	to	-1.99 -2.00	Very dry
			Very dry Extremely

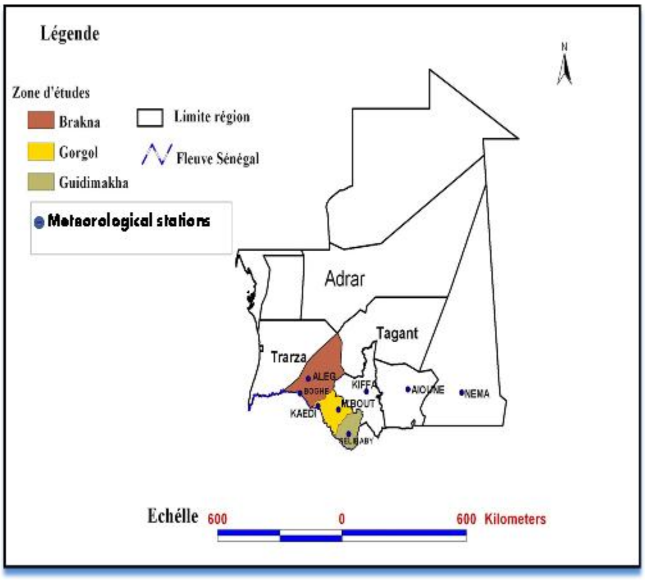

Figure 4: Meteorological stations used at Regional scale

3. RESULTS and DISCUSSION

3.1. Tests for trend detection

Results from hypothesis indicates that the linear correlation coefficient ro=0 is rejected, that means there is a linear trend in rainfall time series as the linear regression coefficient r = -0,38 and the equation: x = 646,58 + -3,63 T

Table 3:Hypothesis Linear correlation

Degrees of freedom	Significance level	Calculated tc	Tabulated tt
56	0,05	-3,12	2,00

The hypothesis of randomness from turning points and Kendall **τ-test** are both accepted

Table 4: Hypothesis: Random series

No points	E (m)	Var (m)	Calculated zc	Significance level	Tabulated z:
40	37,3	9,9	0,84	0,05	1,96

3.2. Test for trend detection changes in variance and means results

The results from Mann-Whitney rank-sum test, T test for detecting change in both variance and mean indicate that there is no change variance and mean as the two series belong to the same population.

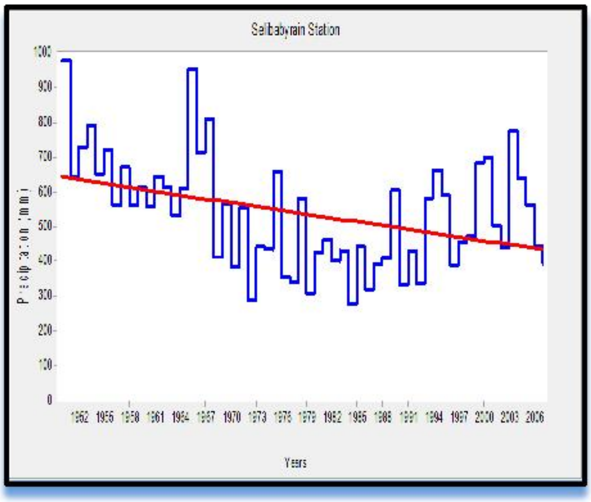

Figure 5: trend detection changes in means plotted by ReDIM

3.3. Run method analysis at Selibaby

By means of the concept of runs, the drought identification was performed using the annual average of the rainfall time series under analysis as a threshold, in a 12-month of aggregation scale.

When the 12-month time scale is applied, a number of 10 annual droughts were detected using 50 % corresponding to the average of annual rainfall as critical thresholds. As shown in figure 6, the maximum drought duration reaches 10 years for the drought of 1979/1980-1988/1989, while the maximum intensity of 192 mm/year was observed for the 1976/77 drought. The average drought cumulated deficit and average drought event duration are respectively 382 mm and 3 years, while the total number of deficit year represents 48 % of the total number of years.

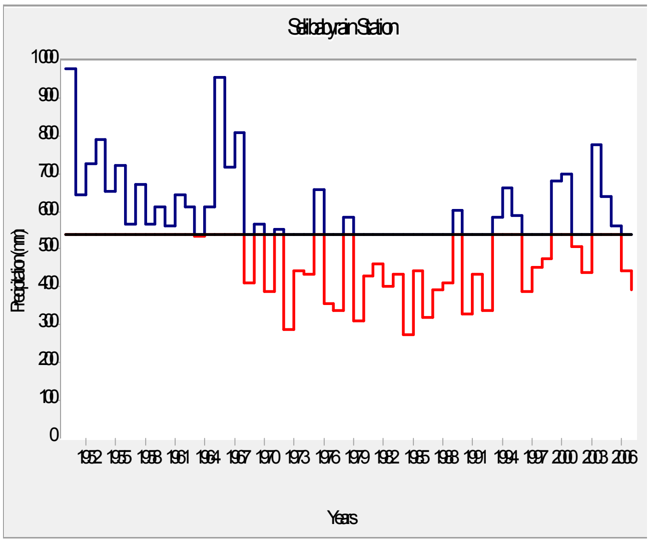

Figure 6: Hydrological variable time series plotted by the ReDIM

The following tables summarize the results of the analysis for the fourth aggregation scale which is one year of observation. Each table gives information about drought identification sorted by date, duration, cumulated deficit and intensity.

Table 5: Drought identification sorted by date

N	Begin.	End	Durat.	Cum. Def.	Drought Int.
			[years]	[mm]	[mm/year]
1	1963	1963	1	6,23	6,23
2	1968	1968	1	125,53	125,53
3	1970	1970	1	151,43	151,43
4	1972	1974	3	449,38	149,79
5	1976	1977	2	384,05	192,03
6	1979	1988	10	1511,56	151,16
7	1990	1992	3	517,48	172,49
8	1996	1998	3	301,98	100,66
9	2001	2002	2	131,45	65,73
10	2006	2007	2	241,55	120,78

Table 6: Drought identification sorted by Cumulated deficit

N	Begin.	End	Duration	Cum. Def.	Drought Intensity
			[years]	[mm]	[mm/year]
1	1979	1988	10	1511	151
2	1990	1992	3	517	172
3	1972	1974	3	449	149
4	1976	1977	2	384	192
5	1996	1998	3	301	100
6	2006	2007	2	241	120
7	1970	1970	1	151	151
8	2001	2002	2	131	65
9	1968	1968	1	125	125
10	1963	1963	1	6	6

Table 7: Drought identification sorted by intensity

N	Begin.	End	Duration	Cum. Def.	Drought Int.
			[years]	[mm]	[mm/year]
1	1976	1977	2	384	192
2	1990	1992	3	517	172
3	1970	1970	1	151	151
4	1979	1988	10	1511	151
5	1972	1974	3	449	149
6	1968	1968	1	125	125
7	2006	2007	2	241	120
8	1996	1998	3	301	100
9	2001	2002	2	131	65
10	1963	1963	1	6	6

Table 8: Drought identification sorted by duration

N	Begin.	End	Duration	Cum. Def.	Drought Intensity
			[years]	[mm]	[mm/year]
1	1979	1988	10	1511	151
2	1972	1974	3	449	149
3	1990	1992	3	517	172
4	1996	1998	3	301	100
5	1976	1977	2	384	192
6	2001	2002	2	131	65
7	2006	2007	2	241	120
8	1963	1963	1	6	6
9	1968	1968	1	125	125
10	1970	1970	1	151	151

The following table summarizes the drought situation based on run method analysis in other sites located in the valley of Senegal River at Mauritania in order to give an outlook on that region. In average of the region, a number of 10 annual drought events (**NDE**) were detected using the same threshold as previously, while a maximum of 13 years of Drought Event Duration (**MDED**) were shown at Boghe station. The average Drought Cumulated Deficit(**DCD**) were evaluated at about 811 mm, while the Maximum Drought Intensity(**MDI**) were about 192 at Selibaby station which represents the reference station of this study. The total number of deficit year represents 51% of the total number of years which is relatively superior to value detected at Selibaby site scale.

Table 9: Run method analysis at other available sites results

longitude	latitude	stations	NDE	MDED	/ period	MDCD	MDI	%TNDY
-11.4	16.63	Kiffa	10	7	1982-1988	729	152	56
-9.6	16.7	Aioun	13	10	1979-1988	818	124	52
-13.92	17.05	Aleg	12	11	1975-1985	780	127	55
-13.5	16.15	kaedi	7	8	1981-1988	467	120	54
-14.28	16.57	Boghe	8	13	1980-1992	1006	99	51
-12.03	16.03	M'bout	9	5	1990-1994	594	133	44
15.817	-16.5	Rosso	9	6	1989-1994	583	131	48
-12.17	15.23	Sélibaby	10	10	1979-1988	1512	192	48

3.4 SPI method analysis at Selibaby site results

Considering the theory of SPI, the drought identification was performed using the SPI=0 as a threshold, in a 12-month of aggregation scale. A number of 10 annual droughts were detected as given in figure 7 using the same definition of drought event as run methods, such is defined as a sequence of intervals characterized by deviations with the same sign preceded and followed by at least one interval with deviation of the opposite sign. That figure indicates also two remarkable breaks in precipitation time series such as 1969 and 1992.

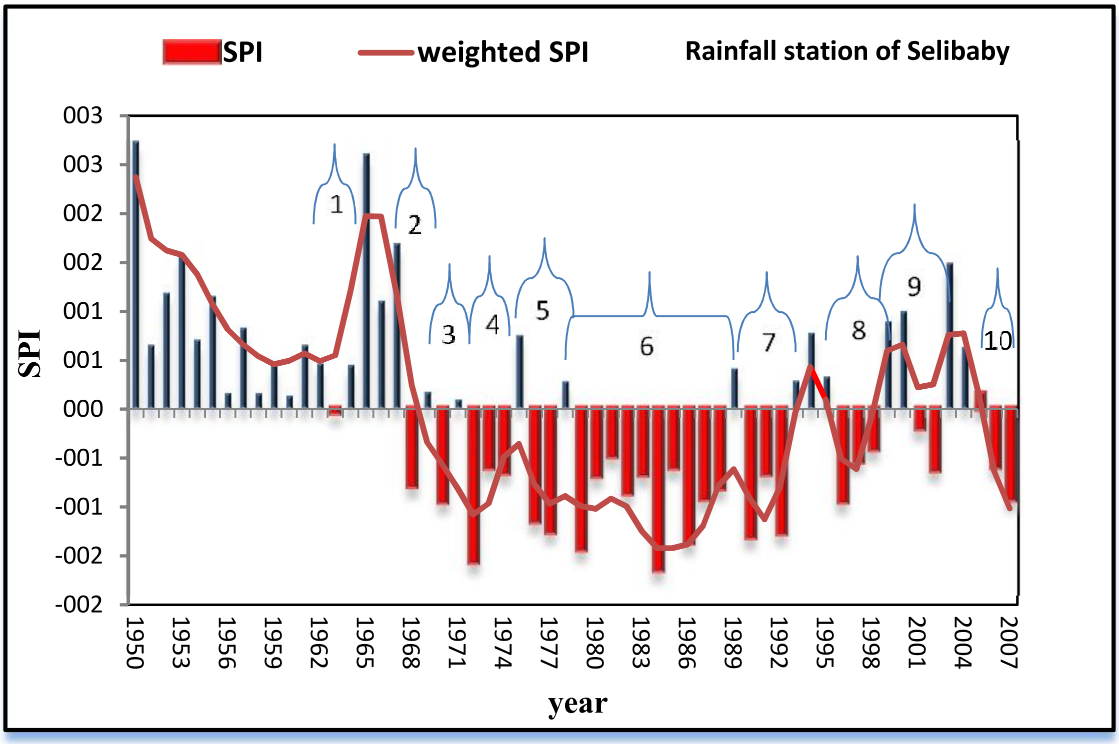

Figure 7: SPI calculated manually using the formula plotted by Excel

Table 10: Drought duration by SPI using two different thresholds

LONGITUDE	LATITUDE	RAINFALL STATIONS	DROUGHT DURATION BY SPI METHOD	DROUGHT DURATION BY RUN METHOD
			THRESHOLD (SEUIL) = SPI< -1	THRESHOLD (SEUIL) = SPI=0
-9,6	16,7	Aioun	11	13
-13,92	17,05	Aleg	8	12
-13,5	16,15	kaedi	6	7
-14,28	16,57	Boghe	9	8
-12,03	16,03	M'bout	6	9
15,817	-16,5	Rosso	6	9
-12,17	15,23	Sélibaby	9	10
-7,27	16,6	NEMA	8	9

Results from the table above indicate clearly that the threshold SPI=0 is more suitable for drought identification we found the same values between run method and SPI method for the threshold SPI=0.

- **SPI drought classification**

Results from the site level drought analysis using the SPI classification are shown in Table 10 for the 12 month time scales, considering a critical threshold of SPI<-1. Complementing the information derived from this classification shown in the table 10, we can remark that, the area affected is concerned by the range very dry to near normal (1,8; 71,1%) respectively.

Table 11: the drought classification at Selibaby site based on SPI values

SPI	% of Number of Months from June to September From year 1951/1952 to 2006/2007	Class
≥ 2.00	5,7%	Extremely wet
From 1.50 to 1.99	1,3%	Very wet
From 1.00 to 1.49	7,0%	Moderately wet
From -0.99 to 0.99	71,1%	Near normal
From -1.00 to -1.49	13,2%	Moderately dry
From -1.50 to -1.99	1,8%	Very dry
≤-2.00		Extremely dry

4. CONCLUSION

Results from rainfall anomalies (SPI), run method and other statistical tests indicate that droughts randomly affect the region. Drought identification shows the alternation of wet periods from 1950-1970 and dry periods from the beginning of the seventies until the end of the nineties and a succession of wet and dry years during the last decade of the period under analysis. Results show that both methods are highly important to characterise drought events both at the site and regional scale, such tools being helpful to assess the climate variability, which strongly affect the rainfed agriculture in the region.

Exposed to the availability of water resources in the future according to hydro-climatic forecasting, it would be useful to investigate more in drought research programs for experimenting other drought indices not only based on precipitation variable but also on other hydro-meteorological data.

In prospect, according to the quality of results produced, this study could bring more added value if it would be reproduced at the Regional scale using a large extend of available meteorological and hydrometric stations in the region of interest (in the valley of Senegal River) from where Mauritania industrial agriculture depends.

Because knowing the proven impact of climate change on water resources and agriculture in the Sahel, Mauritania must reinvigorate its meteorological and hydrometric stations.

It is recommended that further testing and study cases is required to extensively add more to an existing comprehensive, water resources management issues.

Acknowledgements

My special thanks are expressed toward Compagnia di San Paolo (Funding organization), HYDROAID (Promoting organization) and ITHACA (Host Organization) for giving me the opportunity to participate to this Training programme "Formazione per lo Sviluppo 2011". In fact the course was organized by Hydroaid from March 11th to June 11th 2013 in Turin with the financial support of Compagnia di San Paolo.

The REDIM software used in this case is a friendly one which allows to perform drought analysis on hydrological series both at a site and over a region using the method of run and the SPI index and was supported by the Department of Civil and Environmental Engineering University of Catania, Italy within the INCO-DC Project "DSS-DROUGHT" many thanks are due to staff regarding the clearness of the useful reference guide.

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