Drought Climatic Characterization Watershed of Guir (South East, Morocco) using Standardized Precipitation Index (SPI)

Radouan MEHDAOUI[1], El-Mostafa MILI[2]

[1]My Ismail University, Faculty of Science, Department of Geology, BP 11201, Zitoune Meknes, Morocco

Abstract: ***This paper analyzes the spatial and temporal variability of drought in winter season in an arid geographical gradient located in the eastern edge part of the Moroccan High Atlas especially at the Guir watershed. Drought period between 1975 and 2014 were analyzed using the Standardized Precipitation Index (SPI) over 12 months for a 37 year scale. The results indicate that the most important drought by intensity and duration occurred during the 1982/85, 2000/01, and 2012/14 periods are generalized on all stations of the basin with a minimum SPI reached -2. 49 at the Ait Hadou. The results indicate that drought in winter have been tied to the dominance of dry circulation with the exception of the frequency of thermodynamic and north-eastern disturbances which are considered unstable aerological conditions. This happens frequently between February and April each year for the resort of Anoual, Ait Hadou, Ait N'Aissa, Bouanane, Kaddoussa, and Tazougeurt station.***

Keywords: Drought, Standardized Precipitation Index (SPI), Guir Basin

1. Introduction

Drought is defined as a lack of precipitation over an extended period of time, usually a season or more, that has caused a water shortage for an environmental activity, group or sector. Its impacts result from the interaction between the natural event (less precipitation than expected) and the water demand of human activities. Consequently, when the previous water deficit affects surface water bodies (rivers) and groundwater bodies (aquifers), a hydrological drought occurs, because the surface and/or groundwater flow decreases compared to normal values (ABHZGR). Socio-economic drought occurs when insufficient rainfall has a significant impact on communities and their economies. (World Meteorological Organization 1990).

This growing impact requires that drought be considered not only as a natural event to be experienced, but also as a phenomenon to be explained, experienced, and managed effectively and acted upon in advance to mitigate its impact.
Some global change scenarios indicate that the occurrence and impact of droughts are likely to increase in the coming years (Watson et al 1997). In such a climate context, it is essential to be able to analyse meteorological drought sequences in order to propose mitigation or adaptation measures to populations if necessary.

Studies on climate change in Morocco indicate that rainfall is much more contrasted with high spatial-temporal variability, increasing temperatures and a remarkable frequency of drought in recent decades (Elbouqdaoui, et al. 2006 ; Driouech, 2010 ; Sebbar, 2013).

Nevertheless, in the region studied, the negative trend in SPI values is consistent with the increasing frequency of eastern weather types (E, SE), that are likely to cause droughts in this area. Interannual variations in the frequency of different weather types were strongly determined and based on geopotential heights (500 and 1000 hPa levels) for the North Atlantic Europe. The results indicate a significant succession of dry years in the study area, generally negative climatic conditions were observed in winter. It is in this variable and unstable climate context that this study has set itself the objective of analysing meteorological drought sequences on an annual scale in the Guir watershed; to better understand climate evolution and its consequences on a basin scale and to define adaptation strategies.

2. Presentation of the Guir watershed

a) **Geographical situation**
The Guir watershed covers an area of 15206 km². Bounded to the north by the mountains of Ich N'oubiraz, Ichou Almou, Tziba, Asdad, Tiwdersine, Adrar NTassiwant, Al'Agba Tamaqrante and Tioudadine hill whose altitude is 1629m, to the West by the mountains of Golt, Dhart N'bou Ichalmiwne, Bine ElKroun and Ziz watershed, to the South by the mountains of Garet Ziar and hills (whose altitude exceeds 1000 m), and to the East by the mountains of Lakhdar, Bou Ihdoumene, Larwiya Lakbira and hills (whose altitude exceeds 1020 m) Figure 1.

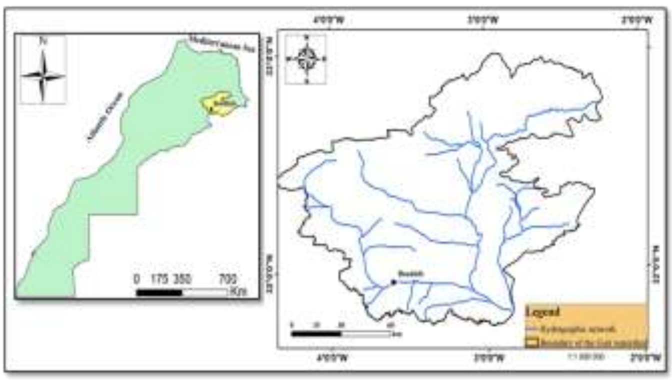

Figure 1: Geographical situation of the Guir watershed

b) Climate Context

From a geo-climatic point of view, the great spatial-temporal variability of the rainfall regime of the zone is due to the orography and its location.

The arched characteristic of the atlasic chain causes the appearance of a shelter zone whose convective system is associated with intense heating. This shelter prevents ocean and marine disturbances from entering the area.

The complexity of climate drought in the basin is accentuated by the instability of cyclonic circulation associated with the presence of topographical barriers; these slow down the disturbed Atlantic and Marine influences, that remain very weak if we take into account the remoteness of the region from the disturbed western and northeastern flows (Figure 2).

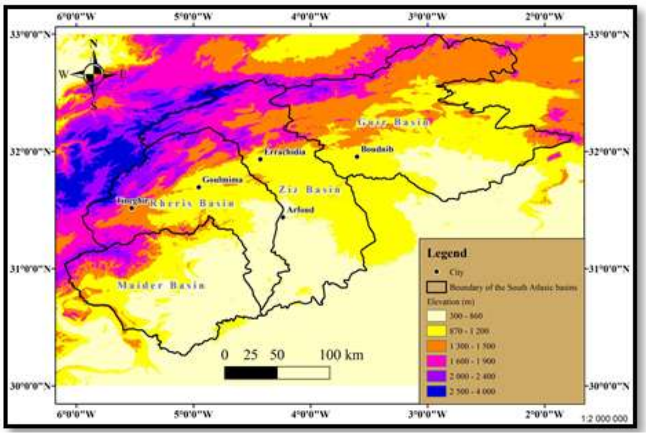

Figure 2: Situation of the area in relation to the local geo-climatic context

Taking into account all the geoclimatic characteristics of the study area, monthly precipitation is found to depend on 75% of the disturbed flows from the northeast sector. Indeed, when a cold valley reaches the western Mediterranean, a disturbed north-easterly flow reaches the eastern regions of Morocco (Figure 3).

In addition, monthly precipitation depends on 20% of thermodynamic thunderstorms which are considered unstable air conditions and occur frequently in Morocco between February and April. These storms are due to the presence of a meridian circulation of cool polar air southward in an environment where there is little contrast between cold polar air and warm tropical air. Upper-air instability is activated by the presence of mountains that force the warm tropical air to rise and in return the polar air at the top to descend (Figure 4).

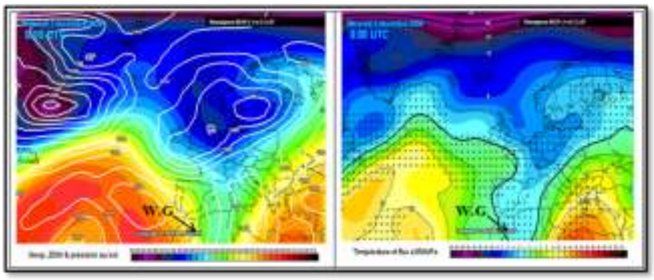

Figure 3: Atmospheric circulation at 500 hPa (hectopascal), from day 3 December 2008 to 00 UTC (Universal Time Coordinated) (http://www.meteociel.fr).

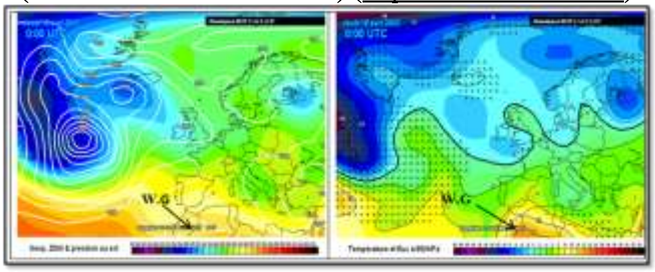

Figure 4: Atmospheric circulation at 500 hPa (hectopascal), from 18 /4/ 2002 to 00 UTC (Universal Time Coordinated) (http://www.meteociel.fr).

Thus, seasonal precipitation patterns also have specific characteristics during the survey period, and mainly monthly, seasonal and annual precipitation that depend on some indigenous specific climatic events, so the interannual variability is quite high.

The main characteristic of the climate in the study area is that it is semi-desert (Saharan) with a strong continental influence. The climate indicators are as follows:

- The average annual rainfall varies from 130 mm at the foot of the High Atlas to 200 mm in the high reliefs; in the basin, it varies from 130 mm in the North to 90 mm in the South.
- The average annual temperature is 19°C with average highs of up to 31°C in July and average lows of 10°C in winter.
- Annual evaporation varies from 3207 mm in Anoual to 3535 mm in Bouanane with extreme values in December and July.
- High winds generally occur between February and September. The average speeds recorded at Bouanane and Anoual are around 3.13 and 2.74 m/s respectively.

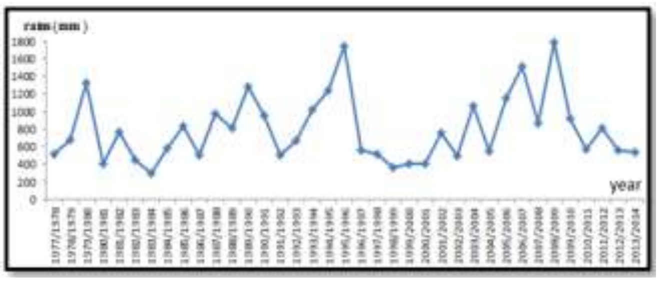

Figure 5: Evolution of annual rainfall in all stations studied (1977/2014 period)

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The annual precipitation regime is characterized by two wet seasons of autumn and spring separated by a short winter season with a low relative minimum, and by a long summer season very marked by drought. In the Guir watershed, the average annual rainfall reaches 250 mm on the summits of the upstream sub-basins, rising to 159 mm at Ait Haddou and 112 mm at Tazouguert. It is irregular with possible successions of five dry years (DRH GRZ, 2008b).

By examining the rainfall data relating to the years 1977-2014, we note that these periods experience a generalized rainfall deficit, whose observation of the graph also makes it possible to distinguish an irregularity from precipitations. The periods 1997-2002 and 2005 are considered dry because the total rainfall is well below the average. In the periods 1994-1996 and 2009 there was an increase in values with more than 1000 mm in almost all stations of the basin. Rainy periods are recorded in October or November, January/February and April or May, while the dry period is generally spread over 5 months. The monthly rainfall is characterized by a very variable rainfall regime. However, from one year to the next, the rainfall deficit can reach 90%, thus causing a rapid drying up of water resources. (Hilali, 2015).

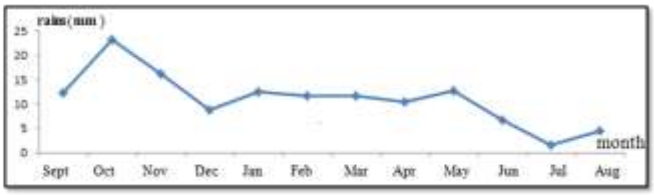

Figure 6: Evolution of average monthly rainfall in the Guir basin

3. Hydrological Context

The watershed of Guir is almost perennial because of the contributions of many sources which compensate the withdrawals for irrigation. The Ait N'Aissa river which is the main tributary feeding Bouanane river also receives important inflows from sources ensuring a sustainable flow. The two rivers (Guir and Bouanane) meet in the Errachidia-Boudnib basin and the Guir leaves Moroccan territory downstream of Ain Chouater.

4. Methodology

The Standard Precipitation Index (SPI) was developed in 1993 by Mc Kee, N.J. Doesken & J. Kleist of Colorado State University, for the determination of rainfall deficits for a given period. It is a powerful index, flexible to use and easy to calculate. Precipitation data is actually the only parameter required. In addition, the SPI is just as effective at analyzing wet periods as it is at analyzing dry periods.

Method of calculating the SPI index

The standardized precipitation index (SPI) is based on statistical calculations of precipitation over a long period (at least 30 years). The SPI was developed in 1993 by Mc KEE, N.J. DOESKEN & J. KLEIST of Colorado State University, for the determination of rainfall deficits. It is a very important index, powerful and simple to calculate. Precipitation data is actually the only parameter required. In addition, the SPI is just as effective at analyzing wet periods or cycles as dry periods or cycles. This index is calculated by the following formula: $SPI = \frac{1}{N_i}\sum_{j=1}^{N_i}\frac{P_j^i-\overline{P_j}}{\sigma_j}$

Where P_j^i is the rain of year i at station j, $\overline{P_j}$ the mean interannual rain of station j, σ_j the standard deviation of the series of seasonal totals at station j and N_i the number of stations of year i.

Positive SPI values indicate precipitation above the median while negative values indicate precipitation below the median. Since the index is standardized, it is possible to represent wet and arid climates in the same way; thus it is also possible, thanks to this SPI index, to monitor wet periods and their repetition frequency (Table 1).

Table 1: Probability of occurrence of climate categories according to (McKee et al 1993)

SPI	Category	Number of times out of 100	Frequency
from 0 to 0.99	Milt drought	33	1 time every 3 years
from -1.0 to -1.49	Moderate drought	10	2 time every 10 years
from -1.5 to - 1.99	Severe drought	5	3 time every 20 years
< -2	Extreme drought	2	4 time every 50 years

The classification adopted by the World Meteorological Organization where seven drought classes are distinguished, ranging from extremely dry to extremely wet, can be distinguished (Table 2).

Table 2: Drought classification according to SPI (OMM)

SPI values Drought category	Drought category
2.0 and higher	Extremely wet
1.50 to 1.99	Very wet
1.0 to 1.49	wet
-0.99 to 0.99	Normal
-1.0 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.0 and less	Extremely dry

A Matlab program for SPI calculation where precipitation data are directly loaded from Excel files has been built. The source of the rainfall data collected and used in this study is the Guir-Ziz-Gheris Watershed Agency. The characteristics of the different stations used in this study are presented in Table 3:

Station Name	Latitude (°, N)	Longitude (°, W)	Elevation (m)	Average annual rains in mm (1977-2014)
Anoual	32.68	-3.09	1200	77.1
Ait Hadou	32.41	-3.77	1412	166
Tit N'Aissa	32.48	-3.78	1150	137.6
Bouanane	32.03	-3.04	860	114
Kaddoussa	32.16	-3.78	1 104	113.8
Tazougeurt	32.08	-3.78	1100	110.9

Tableau 3: Characteristics of the different main hydrometric stations in the Guir basin.

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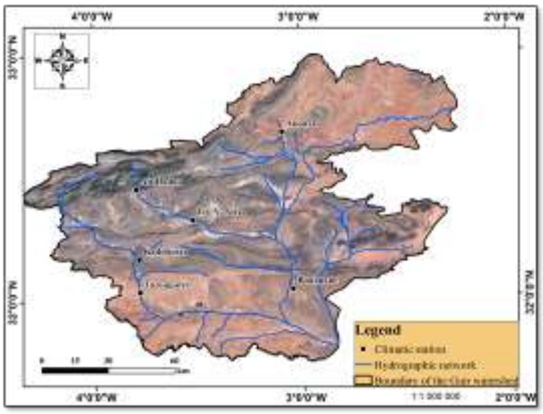


Figure 7: Location map of climate stations located on a satellite background

5. Results and discussions

In order to make a specific analysis at the level of the stations concerned, and to better evaluate the variations in annual rainfall, we calculated the SPI indices for a series of 37 years. The results of the calculation are shown in Figure 8.

a) Anoual Station

The standardized rainfall index at the Anoual station shows a remarkable dominance of dry years during the period (1982-1989 and 2005) we also observe that the SPI index can reach less than (-2.29) for the deficit year 2004/2005, and that explains the existence of drought years.

During the period 93/95 and 2006/2010, there were wet to extremely wet years. While during the period 2010/2014, we notice a drying of the climatic conditions.

b) Ait Hadou Station

From 1977 to 1985 and 1998/2003, the values of the standardized rainfall index at the station level are negative and show moderately dry years with a SPI that can reach less than (-2.49) for the deficit year 1999/2000, with the exception of the years 1979/1980 which is very humid, and from 1987 until 1996 one notices the dominance of normal years.

c) Ait N'Aissa Station

SPI analysis at Ait N'Aissa station indicates the succession of dry and wet years. From 1980 to 1985 and 1996 to 2001 there are moderately dry years, and during the period 2005/2010 there is a succession of moderately wet to very wet years.

d) Bouanane station

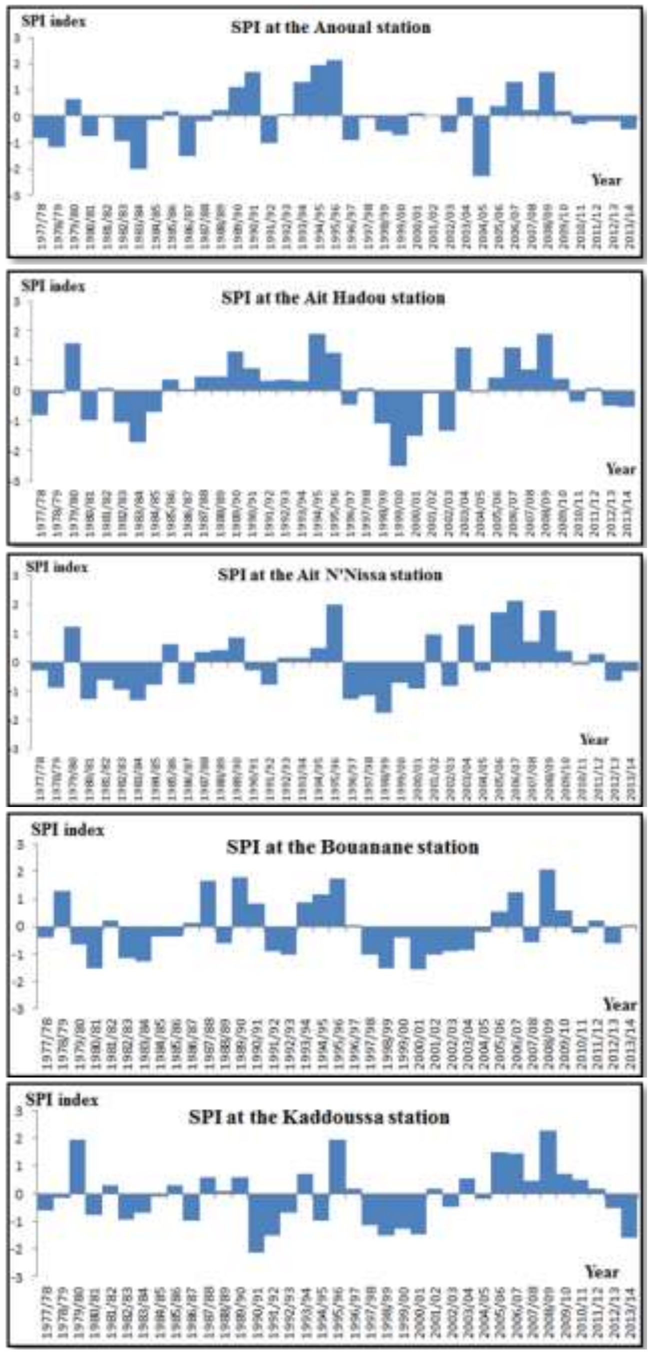
The analysis of the results of the standardized rainfall index at the Bouanane station shows a remarkable dominance of dry periods, where the SPI index can reach less than (-1.52) for the deficit year 2000/2001, so that explains the existence of long dry seasons. We also notice that the years 2006-2011 were wet to extremely wet followed by a drying of the climatic conditions.

e) Kaddoussa station

The analysis of SPI in the Kaddoussa station indicates the succession of dry years (1990/1993 and 1997/2001) where the SPI index can reach less (-2.12) for the deficit year 1990/1991, and wet years (1980, 1996 and 2005/2012), we also note that this zone experienced very dry periods and very wet periods.

f) Tazougeurt station

The SPI analysis in the Tazougeurt station indicates the succession of dry and wet years. There are also extremely hot periods (1984, 1987 and 2001) and extremely wet periods (1980, 1996 and 2009).



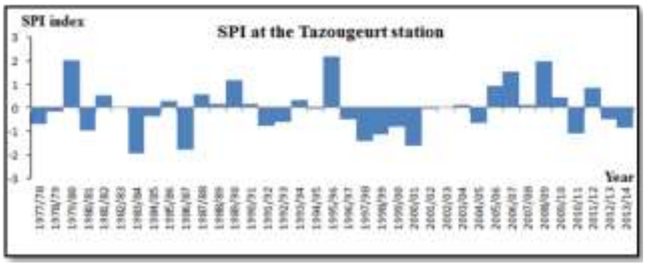


Figure 8: Standardized precipitation index over the period 1977-2014 at the eight climate stations in the Guir watershed

SPI value	Category	Number of years	Number of times over 100 years	Frequency (Ait Hadou Station)
2<SPI	Extremely wet	0	0	No occurrence
1.5<SPI<1.99	Severely wet	3	8	1 time every 12 years
1<SPI<1.49	Moderately wet	4	11	1 time every 9 years
0<SPI<0.99	Mildly wet	14	38	1 time every 3 years
0<SPI<-0.99	Mild drought	10	27	1 time every 4 years
-1<SPI<-1.49	Moderate drought	3	8	1 time every 12 years
-1.5<SPI<1.99	Severe drought	2	5	1 time every 19 years
SPI < -2	Extreme drought	1	3	1 time every 37 years

SPI value	Category	Number of years	Number of times over 100 years	Frequency (Anoual Station)
2<SPI	Extremely wet	1	3	1 time every 37years
1.5<SPI<1.99	Severely wet	3	8	1 time every 12 years
1<SPI<1.49	Moderately wet	3	8	1 time every 12 years
0<SPI<0.99	Mildly wet	10	27	1 time every 4 years
0<SPI<-0.99	Mild drought	15	41	1 time every 2 years
-1<SPI<-1.49	Moderate drought	2	5	1 time every 19 years
-1.5<SPI<-1.99	Severe drought	1	3	1 time every 37 years
SPI < -2	Extreme drought	2	5	1 time every 19 years

SPI value	Category	Number of years	Number of times over 100 years	Frequency (Ait N'Aissa Station)
2<SPI	Extremely wet	2	5	1 time every 19 years
1.5<SPI<1.99	Severely wet	2	5	1 time every 19 years
1<SPI<1.49	Moderately wet	2	5	1 time every 19 years
0<SPI<0.99	Mildly wet	11	30	1 time every 3 years
0<SPI<-0.99	Mild drought	15	41	1 time every 2 years
-1<SPI<-1.49	Moderate drought	4	11	1 time every 9 years
-1.5<SPI<-1.99	Severe drought	1	3	1 time every 37 years
SPI < -2	Extreme drought	0	0	No occurrence

SPI value	Category	Number of years	Number of times over 100 years	Frequency (Bouanane Station)
2<SPI	Extremely wet	1	3	1 fois tous les 37 years
1.5<SPI<1.99	Severely wet	3	8	1 fois tous les 12 years
1<SPI<1.49	Moderately wet	3	8	1 fois tous les 12 years
0<SPI<0.99	Mildly wet	9	24	1 fois tous les 4 years
0<SPI<-0.99	Mild drought	13	35	1 fois tous les 3 years
-1<SPI<-1.49	Moderate drought	5	14	1 time every 7 years
-1.5<SPI<-1.99	Severe drought	3	8	1 fois tous les 12 years
SPI < -2	Extreme drought	0	0	No occurrence

SPI value	Category	Number of years	Number of times over 100 years	Frequency (Kadoussa Station)
2<SPI	Extremely wet	1	3	1 time every 37 years
1.5<SPI<1.99	Severely wet	2	5	1 time every 19 years
1<SPI<1.49	Moderately wet	2	5	1 time every 19 years
0<SPI<0.99	Mildly wet	13	35	1 time every 3 years
0<SPI<-0.99	Mild drought	12	32	1 time every 3 years
-1<SPI<-1.49	Moderate drought	3	8	1 time every 12 years
-1.5<SPI<-1.99	Severe drought	3	8	1 time every 12 years
SPI < -2	Extreme drought	1	3	1 time every 37 years

SPI value	Category	Number of years	Number of times over 100 years	Frequency (Tazougeurt Station)
2<SPI	Extremely wet	2	5	1 time every 19 years
1.5<SPI<1.99	Severely wet	2	5	1 time every 19 years
1<SPI<1.49	Moderately wet	1	3	1 time every 37 years
0<SPI<0.99	Mildly wet	13	35	1 time every 3 years
0<SPI<-0.99	Mild drought	13	35	1 time every 3 years
-1<SPI<-1.49	Moderate drought	3	8	1 time every 12 years
-1.5<SPI<-1.99	Severe drought	3	8	1 time every 12 years
SPI < -2	Extreme drought	0	0	No occurrence

Figure 9: Probability of occurrence of each category for the six climate stations of the Guir watershed during the period (1977-2014)

The graph in Figure 10 reflects the correlation that exists between the average annual flow of Tazougeurt river recorded during the period 1977/2007 and the 12-month SPI at the same rainfall station, and confirms the hydrological response of river to rainfall.

Drought monitoring by the SPI can be used to monitor pasture conditions in the Guir watershed.

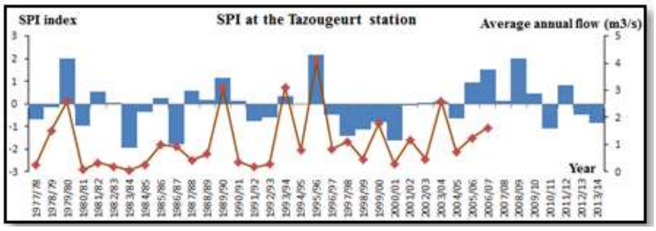


Figure 10: Correlation between Tazougeurt SPI and average annual Guir river flow (1977/2007)

Figure 11 shows the degree of drought by calculating the ratio index for the driest and normal year of rainfall, and its rainfall deficit equivalent for each year. Thus, during the study period, 21% of years have a water reserve surplus, while a deficit of less than 50% represents 24% of years, and 54% of the period has a deficit of more than 50%.

Figure 11: Drought episodes in the Guir watershed during the period (1977/2014)

6. Conclusion

This work showed that the Guir watershed experienced severe drought periods with a significant rainfall deficit during the period 1997/2001 and 2011/2014.

The results obtained after the calculation of the standardized precipitation index made it possible to locate drought sequences in the stations studied:

- Anoual station: from 1977 to 1988 and 1997 to 2005, moderately dry years were observed;

- Ait Hadou station: for the period 1997 to 2003, results show very dry years;
- Ait N'Aissa station: for the period 1981 to 1985 and 1996 to 2001, the SPI index shows extremely dry years;
- Bouanane station: some years are very dry and others are extremely dry.
- Tazougeurt station and Kaddoussa station: for the period 1991 to 1993 and 1997 to 2002, the SPI shows some dry years and others are extremely dry.
- The study of the probability of occurrence shows that the most frequent climatic categories are those of light wet climate and light drought.

The orography and elevation of the High Atlas have a positive influence on precipitation in the northern part of the basin.

The drought according to the SPI index showed a trend towards an increase in the recurrence of dry years starting in 1977 in the Guir watershed.

The study presents a system for monitoring water situations through hydro-climatic indicators that define the different states of drought: Alert, Early Warning and Emergency and the thresholds above which a given state of drought must be declared.

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