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Climatic Drought Characterization Using the Standardized Precipitation Index (SPI) and the North Atlantic Oscillation (NAO) Effects in the Tensift Watershed-Morocco

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ABSTRACT: Drought is a complex natural phenomenon and does not have a precise definition. The frequency of this meteorological and climatic phenomenon has been intensifying in recent decades. It is the most serious natural risk for Morocco's economy and its future given its harmful impacts. In this work, we study this phenomenon in the Tensift watershed using monthly rainfall series from three weather stations (Aghbalou, Chichaoua, Adamna), they represent the three parts of the basin (upstream, median and downstream). We use the Standardized Precipitation Index (SPI) calculated on several time scales. This allowed us to characterize the fluctuations of this phenomenon, which has become more pronounced during the last decades. We also present the correlation that exists between the SPI values that characterize the amount of rainfall and drought with the North Atlantic Oscillation index as an explanatory factor of this rainfall variability in the region.

KEYWORDS: Tensift; monthly rainfall series; drought; SPI; NAO.

1 INTRODUCTION

The issues related to the persistence or not of the drought are of primary importance for the countries and the inhabitants of the arid and semi-arid regions. Updating the results obtained is therefore an element of knowledge, both to assess current environmental constraints and to optimally manage a scarce resource [3]. On the other hand, drought is manifests itself only by certain indices and parameters, several researchers have tried to identify them. These indices make it possible to identify the different types of drought (meteorological, agricultural and hydrological), its intensity, its duration, its spatial extent and its probability of recurrence. Most of these indices are based on two concepts namely: the normal year, and the line that indicates the drought.

Morocco has experienced severe droughts that have affected its water resources both qualitatively and quantitatively. During its history, numerous droughts of varying magnitude have plagued it; some of which have had sometimes-dramatic repercussions on the living conditions of the population, in particular, rural [13]. Thus, Drought is the major natural risk that threatens the country's resources [2] and it can have several impacts on agriculture, hydrology and consequently on society and its economy [8].

The objective of our work is to characterize the climatic drought in the Tensift basin for the period 1972-2015, through the calculation of a rainfall index on an annual scale. Next, we propose to identify the probability of occurrence of different severity classes of drought by station. Finally, we will analyze the relationships between drought and the North Atlantic Oscillation Index (ONA) and make hypotheses that can explain the spatio-temporal variability of the climatic drought in Morocco.

2 GEOGRAPHICAL LOCATION

Located in the center of Morocco, the Tensift basin constitutes one of the basins of Morocco, which is characterized by the concentration of important socio-economic activities. It is limited to the west by the Atlantic Ocean and by the Atlas range to the east and south, the study area is located in the center of Morocco between latitudes 32° 10’ and 30° 50’ North and longitudes 9° 25’ and 7° 12’ West. The Tensift spreads over an area of approximately 25,200 km2. It is limited to the south by the ridgeline of the High Atlas range, to the north by the massif of small mountains named "Jbilet" with altitudes below 1000 meters, to the east by the watershed, and to the west by the Atlantic Ocean where its outlet is located. The altitudes are therefore very contrasting, up to 4167 meters at Jbel Toubkal.

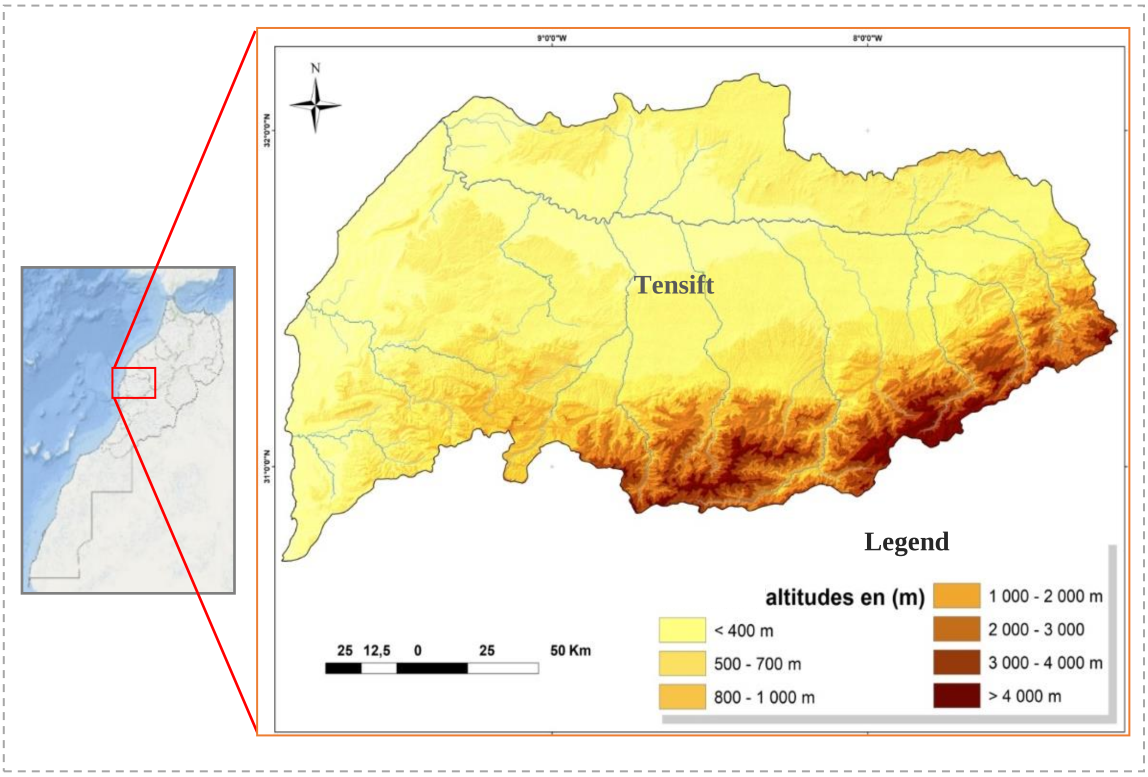

Fig. 1. Geographical location of the Tensift watershed

3 METHODOLOGY

3.1 THE DATA USED

The instrumental data recorded by the measuring stations are considered the most reliable source for the detection of recent climate change. In fact, the rainfall data collected mainly come from the Tensift Hydraulic Basin Agency (ABHT). These data that we are going to exploit are spread over a period of 43 years (1972-2015). They represent the three parts of the basin (upstream, median and downstream). The variability of the quality and duration of the chronicles required a choice of stations based on three criteria: the duration of the chronicle (covering the largest possible period of time), the importance of the gaps (as few missing data as possible) in it as well as their geographical position relative to the basin.

The objective is to identify the variability of rainfall, their trends and above all to identify the phases of drought. The different time steps used in this work make it possible to characterize the amplitude and frequency of the meteorological drought that the Tensift basin has experienced. The correlation of these values with the NAO index was also highlighted in order to understand the atmospheric connections of drought in the study area.

3.2 METHODOLOGY

Several methods and indices have been developed for this purpose in order to characterize and identify climatic drought at different time scales (annual, seasonal). In order to determine the wet or dry character of a year or a season, the standardized precipitation index (ISP) is usually used. This index, called Standardized Precipitation Index in the English literature (SPI), is an average of the rainfall totals (annual or seasonal) centered and reduced calculated at each available station for a given year or season. It is intended to indicate by itself whether the season or the year can be qualified as surplus (SPI> 0) or deficit (SPI < 0) [1].

The standardized precipitation index (SPI) is the most widely used indicator in the world to detect and characterize meteorological drought. The SPI index, developed by [12], described in detail by [6]. The choice of the standardized precipitation index is linked to the fact that this index has advantages in terms of statistical consistency and the ability, to describe and quantify the precipitation deficit at multiple time scales. It also makes it possible to analyze wet periods as well as dry periods and can ensure early warning of drought and help them assess its severity.

The mathematical formula of SPI is as follows:

SPI = (pi - pm) / σ

Where:

Pi: Precipitation of the year i

Pm: Average precipitation

σ: Standard deviation or standard deviation

A drought occurs when the ISP is consecutively negative and its value reaches an intensity of -1 or less, and ends when the ISP becomes positive. A classification of the drought is carried out according to the values of the ISP.

Table 1. SPI Classifications

2.0 and more	Extremely wet
de 1,5 à 1,99	Very wet
de 1,0 à 1,49	Moderately moist
de -0,99 à 0,99	Close to normal
de -1,0 à -1,49	Moderately dry
de -1,5 à -1,99	Very dry
-2 and less	Extremely dry

4 RESULTS AND DISCUSSION

The global variability of the climate in the short term is generally associated with phases of coupled oceanic and atmospheric phenomena including the North Atlantic Oscillation (ONA), which represents the dominant climate mode in the North Atlantic region [9]. To identify the correspondence between the drought and the North Atlantic Oscillation Index (ONA), and explain the spatio-temporal variability of the climatic drought in the Tensift watershed, we are led to analyze their annual evolutions with the ISP precipitation index of the three stations Aghbalou, Chichaoua, Adamna during the study period (1972-2015). In order to make a punctual analysis at the level of the rainfall stations selected in this study, and to better assess the variations in annual rainfall, we calculated the SPI index.

4.1 THE SPI INDEX OF THE THREE RESORTS OF AGHBALOU, CHICHAOUA AND ADAMNA

The analysis of the SPI values shows that before 1980, very few dry sequences were observed in most of the stations studied (Fig.2). Thus, from 1972 to 2015, 08 dry sequences, 11 dry sequences and 09 dry sequences were respectively observed at the stations of Aghbalou, Chichaoua and Adamna for the period 1978-2015. Indeed, the SPI statistical index revealed that the period 1983-1984 in the watershed of the Tensift experienced a significant rainfall deficit. Indeed, the calculation of the standardized rainfall drought index of the Tensift watershed from the hydrological year 1972 to 2015 shows the alternation of dry and wet sequences during the studied period. It is also noted that the maximum duration of drought in this study area is at least 4 years. The Aghbalou resort has experienced periods of 2 successive years of drought (1983-1984 and 1986-1987), with peaks in 1979, 1983, 1987, 1993 and 2005, these peaks were characterized by droughts of extremely severe types. Whereas, the periods 1972-1974 and 1988-1989, 1996-1999 and 2009-2011 are generally humid. This station has also been marked by periods of 3 and 4 successive years close to normal (1975-1977, 2012-2014 and 1997-2000). Indeed, this station is marked by a spatio-temporal irregularity of the rains.

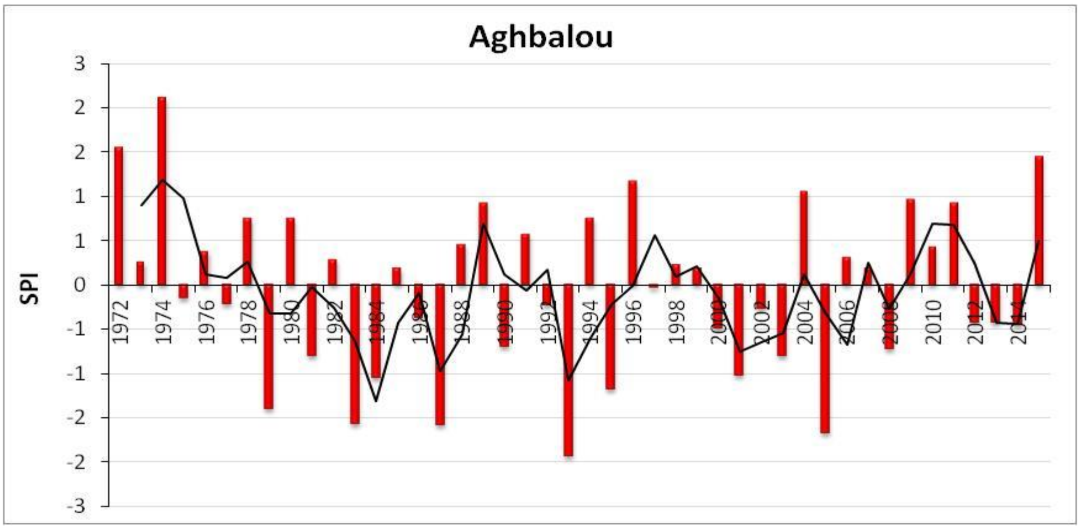

Fig. 2. Evolution of the meteorological drought using the SPI index at the Aghbalou station (1972-2015)

At the Chichaoua station, we notice the alternation of wet and dry periods during the study period with a succession of wet and relatively normal phases sometimes exceeding 5 years, are recorded in the period of 1988-1991, 1994-1998 and 1978-1980. While, this resort has also experienced periods of droughts of 2 successive years of drought (1983-1984, 1992-1993 and 2001-2002), with peaks in 1981,1983, 1993, 2001 and 2005, these peaks have been characterized by strong and extremely severe types of droughts.

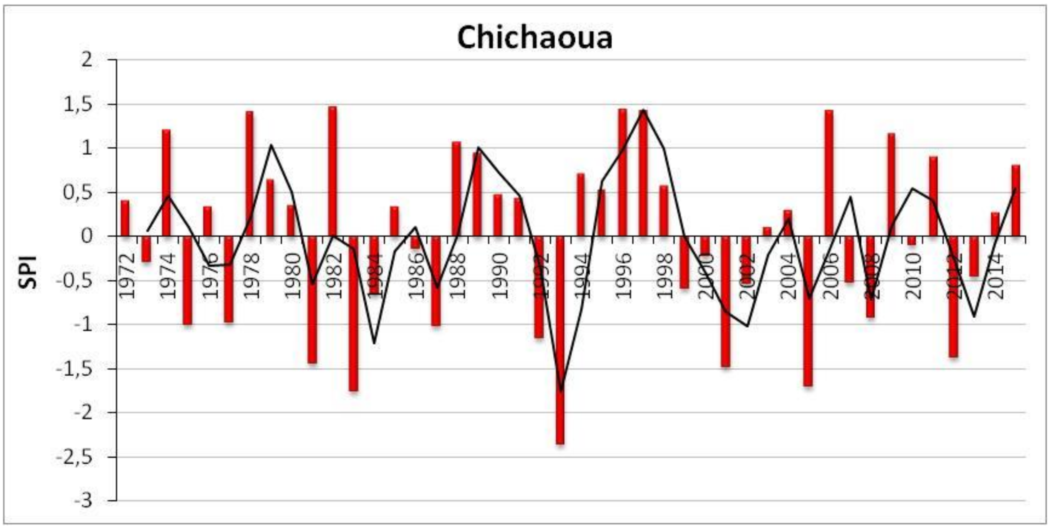

Fig. 3. Evolution of the meteorological drought using the SPI index at the Chichaoua station (1972-2015)

The analysis of the standardized precipitation index (SPI) for the Adamna station revealed that this station experienced a significant rainfall deficit from the 80s with peaks in 1987, 1992, 2007 and 2008. These peaks were characterized by droughts of strong and extremely severe types. During the period of 1978-2015, Adamna station recorded more drought sequences, it experienced periods of 2 successive years of drought (1992-1993, 2007-2008), with relatively normal periods of 3 and 4 successive years (1984-1986, 1989-1991, 2002-2004, 2012-2015).

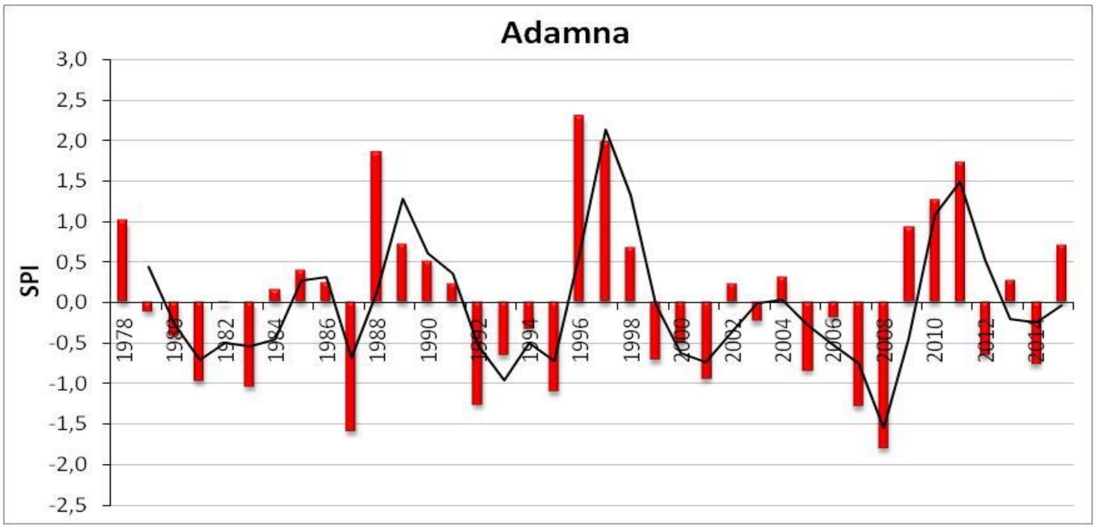

Fig. 4. Evolution of the meteorological drought using the SPI index at the Adamna station (1972-2015)

On the other hand, the percentage of dry and wet years in the Tensift watershed does not each exceed the threshold of 25% over the period 1972/2015. On the other hand, we notice the dominance of years close to normal, which have a percentage of around 60% (Fig.5).

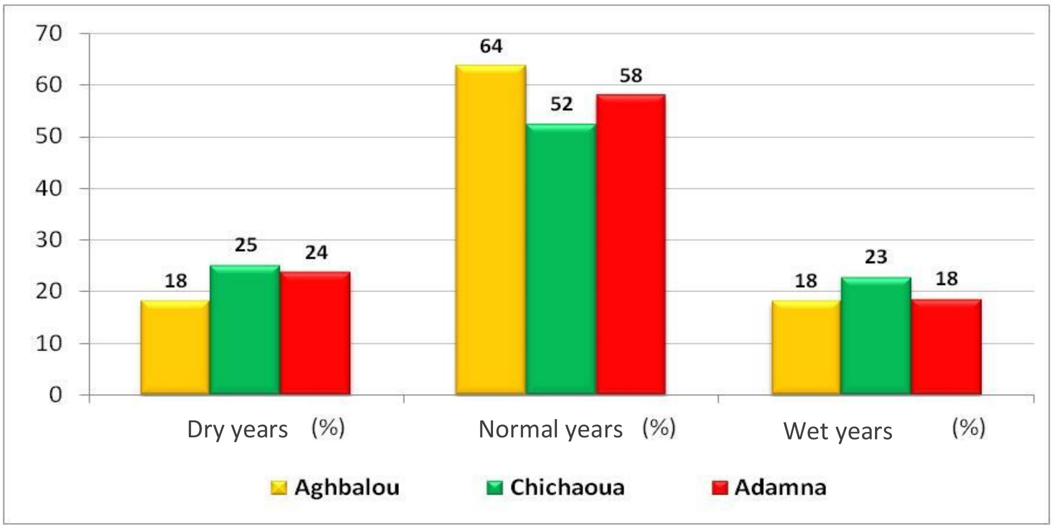

Fig. 5. Percentage of dry, normal and wet years at Tensift (1972-2015)

The study of the drought indices at the level of the watershed of the Tensift generally highlights two periods, the relatively surplus years start from 1988 until 1998, comes after the deficit years between 1999 and 2008, its periods are interrupted by dry or wet years depending on the period. While, the period between 1996-1998 are remarkably humid, and the years 1983 and 1993 are extremely severe at the level of the three stations.

4.2 Correlation Of The ISP Index With The North Atlantic Oscillation Index (ONA) In The Tensift

Atmospheric circulation is the main factor in the changes in the severity of the seasons, especially winter, from one year to another. Among the most distinguished elements of the interannual variability of large-scale atmospheric circulation is the importance of the spatial organization of teleconnection modes [10].

In this regard, it is important to be able to distinguish whether these climatic variations that characterize our study area (Tensift Basin) are connected to phenomena of wider spatial and temporal amplitudes, or if they are only an expression of local effects. Several studies have linked climatic variations (precipitation) to climate fluctuations [10; 5; 14; 4; 10] in order to understand the abrupt changes, fluctuations and trends observed.

At the level of the three stations of the Tensift watershed for 44 years (1972-2015), the correlation of their SPI index with the teleconnection mode (NAO) revealed significant values. Which shows the influence of this mode on the rainfall regime of these stations.

On an annual scale, the SPI index showed that the dry years in Aghbalou correspond to the years 1979, 1983, 1984, 1987, 1993, 1995, 2001, 2005, of which 62% coincide with the positive phase of NAO. On the other hand, the peak of the 1972, 1974, 1996, 2004 and 2015 wet episodes can be linked to a low negative NAO index (fig.6).

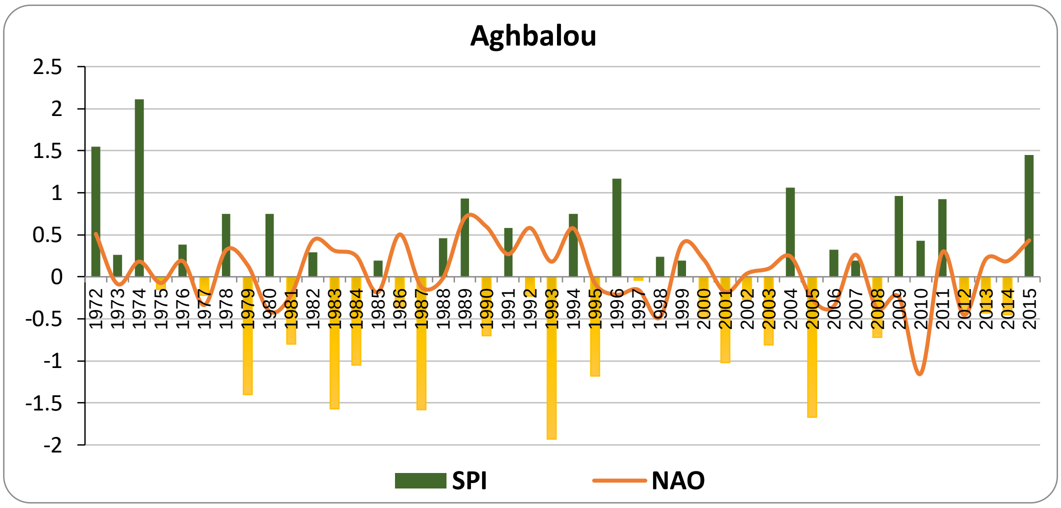

Fig. 6. Evolution of the NAO indice with the SPI index of Aghbalou precipitation on an annual scale during the period 1972-2015

The annual variations in the SPI index of precipitation in Chichaoua during the study period showed that the episodes of 1981, 1983, 1993, 2001, 2005 and 2012 present the strong and extremely dry episodes of the period 1972-2015. With a simple calculation we find that 33% of these periods coincide with the positive phases of NAO. In contrast, the peak of the wet years recorded in 1974, 1978, 1982, 1996, 1997, 2006 and 2009 can be put in relation to a low negative NAO index (fig.7).

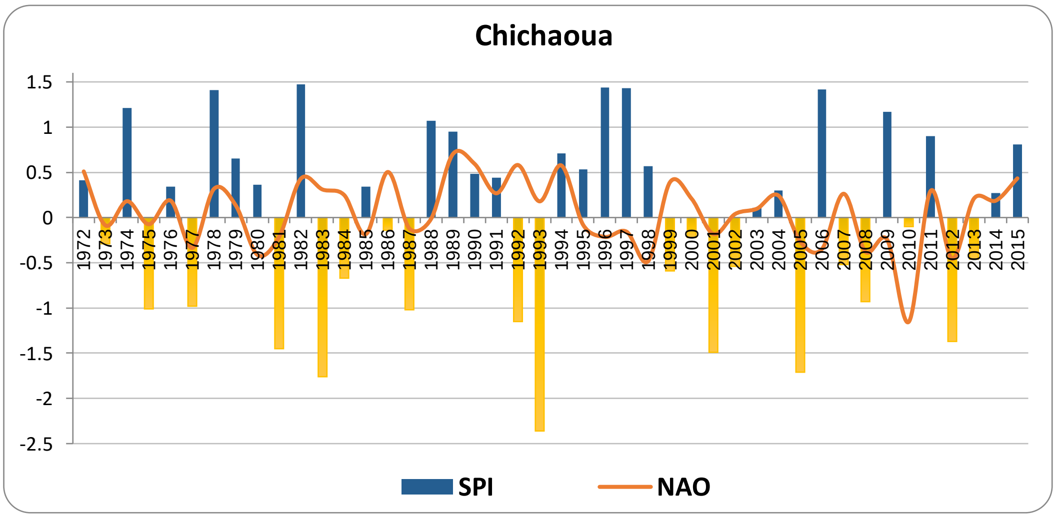

Fig. 7. Evolution of the NAO indice with the SPI index of Chichaoua precipitation on an annual scale during the period 1972-2015

For the Adamna station on an annual scale (1978-2015), the SPI index showed that the years 1981, 1983, 1987, 1992, 1995, 2007 and 2008 of are the driest years at this resort. So, with a simple calculation we find that 57% of these periods coincide with the positive phases of NAO, which explains the reduction in rainfall during these periods. This is also explained by the reduced effect of these modes, which generally remains fable. On the other hand, the peak of the 1988, 1996, 1997, 2010 and 2011 wet episodes can be linked to a very strong negative NAO index, in particular the years 1997, 2010 and 2011 (fig.8).

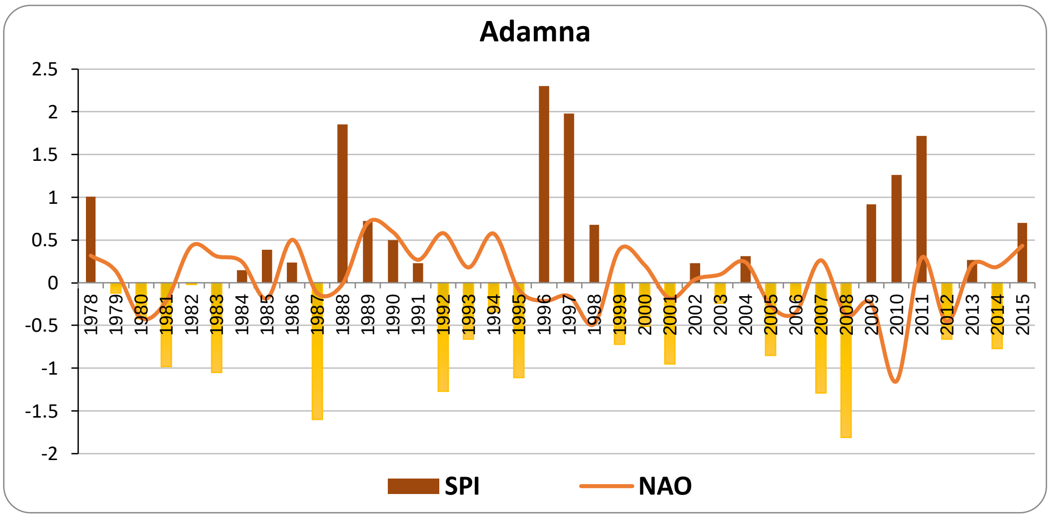

Fig. 8. Evolution of the NAO indice with the SPI index of Adamna precipitation on an annual scale during the period 1978-2015

We analyzed the correlations between the three rainfall series and the climate index (NAO). On an annual scale, it appears that annual precipitation is positively correlated with NAO. The positive correlation means that the precipitation of NAO evolves in the same direction on a temporal scale. The analysis of the relationships between the dry episodes (ISP) and the positive phases of NAO, highlights significant correlation in the stations of Souss-Massa. Overall, it appears that the study area is influenced by the NAO index.

5 CONCLUSION

The study of the indices of the previous drought at the level of the watershed of Tensift generally brings out surplus periods and deficit periods, its periods are interrupted by dry or wet years during the period studied. By the way, the study of the drought indices (PSI) at the level of the watershed of the Tensift generally highlights two periods, the relatively surplus years start from 1988 until 1998, comes after the deficit years between 1999 and 2008, its periods are interrupted by dry or wet years depending on the period. While, the period between 1996-1998 are remarkably humid, and the years 1983 and 1993 are extremely severe at the level of the three stations.

The correlations between the three rainfall series and the climate indices (NAO). On an annual scale, it appears that annual precipitation is positively correlated with NAO. The positive correlation means that the precipitation of NAO. The analysis of the relationships between the dry episodes (ISP) and the positive phases of NAO, highlights a significant correlation for the Tensift, it therefore appears that the basin is influenced by the NAO index.

The influence of the NAO on the rainfall of this region has been well demonstrated, but it is weakened by advancing towards the interior of the country. Other factors of an atmospheric or orographic nature participate in this result. In general, the rainfall in the study area and throughout Morocco is mainly the result of very rapid westerly disturbances accompanied by shallow atmospheric depressions (Knippertz. P, et al. 2003).

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