[01062] ANALYSIS OF METEOROLOGICAL DROUGHT SEQUENCES IN THE TENSIFT WATERSHED: IMPACTS ON THE ANNUAL INFLOWS TO THE TAKERKOUST DAM AND ON WATER ALLOCATION FOR IRRIGATION

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ABSTRACT

Tensift Watershed, located in the mid-western region of Morocco is vulnerable to droughts. Data analysis on rainfall over a period of forty-six years (1968-2014) has allowed determining wet and dry periods. We used the analysis of trend curves and the standardized precipitation index (SPI) to highlight the temporal evolution of periods of droughts. The trend observed showed that the watershed experienced the most significant wet periods during the years 1970-1978, followed by a succession of dry periods of varying intensities extending to the years of 2007/2008. From this period up to the year 2011, a return of rainfall was observed, but with less intensity than in the 1970-1978 period. Another period of declined rainfall intensity occurred starting from the year 2011. Droughts experienced in the Tensift watershed have negatively affected water supply to the Takerkoust dam, and therefore the amount of water allocated for irrigation.

Keywords: Drought, SPI, Tensift watershed of Morocco, water allocated for irrigation, water supply.

1. INTRODUCTION

In arid and semi-arid Mediterranean regions, including Morocco, the scarcity of water resources is nothing new. In fact, Morocco has not been spared from the known droughts in recent decades that have affected the Mediterranean basin, manifesting themselves particularly in a severe and persistent manner, and with remarkable extent (Sebbar et al., 2011).

In fact, Morocco has experienced rainfall deficits, leading to severe droughts with significant imbalances of water resources in the country, quantitatively and qualitatively. Several regions of Morocco have experienced a series of dry periods since early 1980 resulting to significant economique consequences (Driouech, 2010).

Morocco has experienced significant increase in temperatures during the period between 1961 and 2008 with a general trend toward droughts being observed. Most annual trends are between 0.2°C and 0.4°C per decade (Driouech, 2010) and decreased rainfall is almost the case throughout the Moroccan territory. Research has confirmed, through the study of rainfall deviations from the average annual rainfall of Morocco (1934-2000), erratic rainfall and showed a significant decrease in water supplies since 1980 (and Amraoui al., 2004).

Global climate change scenarios indicate an increased trend of the occurrence and impact of droughts in the near future (Watson et al., 1997). Several other studies of future climate projections using climate models show that Morocco is one of the countries most likely to be affected by climate change and would record a reduction in cumulative rainfall by the end of the current century (IPCC, 2007). Climate projections by the National Directorate of Meteorology predict an increase in average summer temperatures by 2°C to 6°C and 20% reduction in average rainfall by the end of the century.

The Tensift watershed, located in mid-west Morocco, contains the High Atlas Mountains and the semi-arid central plain of Haouz. Agricultural irrigation accounts for more than 85% of water uses. The climatic regime of the watershed is Upper-arid, essentially conditioned by altitude and to a lesser extent by the continentality (Riad, 2003). Rain is often concentrated during fall and winter. It is generally irregular, intense and violent.

The present study deals with the assessment of historical occurrence of droughts in the Tensift river basin (Morocco) in order to better understand their frequency of occurrence and their impact on water supply for dams. This region shelters a large agricultural production area, which is fed for water for irrigation from dams reservoirs.

2. MATERIALS AND METHODS

2.1 Study area

The Tensift river basin is one of the most important watersheds of Morocco that shelters significant socioeconomic activities, including agriculture and tourism. Located in the mid- west region of Morocco (Figure 1), it covers an area of 20,450 km².

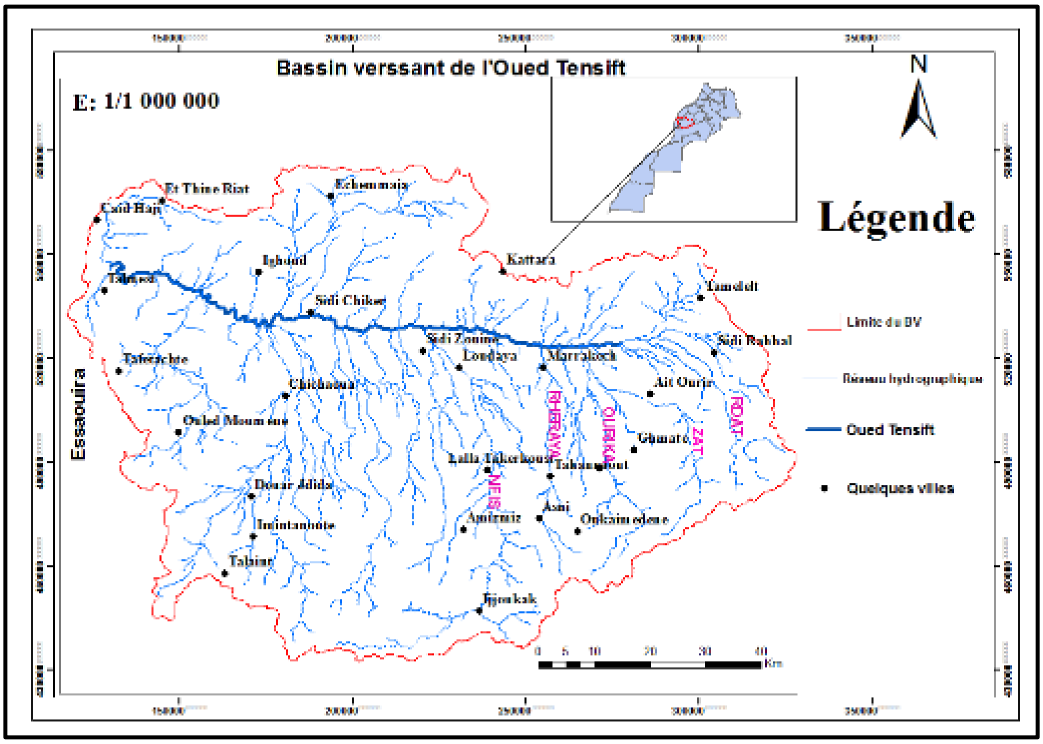

Figure 1. Presentation of the Tensift watershed

Administratively, this area covers six prefectures and provinces; completely including the prefecture of Marrakech and Al Haouz, Chichaoua and Essaouira provinces, and partially the provinces of El Kalaa des Sraghna and Safi. Due to its size and landscape, the region is characterized by a highly differentiated climate zone, influenced by both the distance from the sea and the closeness of Atlas Mountains. Consequently, its climate is semi-arid with a winter influenced by the cold Canary Current in the Essaouira region, semi-arid continental to semi-temperate in the Bahira plain, hot semi-arid in Jbilet and Mouissate, and arid continental in the Haouz and Mejjate plains.

2.2 Data

The data used came from several sources including the Regional Office of Agricultural Development of Marrakech (ORMVAH), which has rainfall stations in several centres of agricultural development (CMV), scattered throughout the Tensift watershed. The rest of data was collected from the Tensift Watershed Hydraulics Agency (ABHT). Rainfall data from twenty-four stations distributed in the Tensift watershed covering the period between 1968 and 2014 (Table 1) were used. Missing data were completed using altitude gradient model established for climate areas of High Atlas of Marrakech (Ouhammou, 2005). Water supplies in the Takerkoust dam and the annual volume of water allocated to agriculture were provided by ORMVAH for the period 1985-2014.

2.3 Analysis of rainfall variability and impact on water supply

Analysis of rainfall variability in space:

We conducted an analysis over the whole basin. The objective was to find out, from the various observations of precipitation, the height of equivalent and uniform rainfall in the watershed (H_{EU}). Rainfall in the watershed is spatially variable, in addition to its temporal variability, which becomes significant with varying altitude, terrain, wind speed distribution and geographical scope.

Given the large spatial variability, the preferred method was the weighted average by Thiessen polygons. This method estimates the weighted values, taking into consideration each rainfall station. In fact, at every rain gauge, a zone of influence whose area expressed in percentage is the weighting factor of the local value. The idea is to join the nearest stations by straight lines, tracing the mediators of these segments. These mediators are to form polygons (areas) limiting the influence of each station area. Rainfall is then assumed uniform within the surface of polygons S_i. The equivalent and uniform rainfall height in the watershed (H_{EU}) is determined by the following formula:

H_{EU} (mm) = $(S_1*P_1 + S_2*P_2 + \ldots + S_nP_n)/S_t$

The weights were assigned to different stations and the annual average for the basin scale determined.

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Analysis of the rainfall variability in time:

First analysis consist of graphical visualization of rainfall distributions as a function of years. Second, the graphs were examined for both raw and smoothed series by the moving average technique. The chosen period was 5 years. These smoothed averages reduce the amplitude of inter annual fluctuations and produce sharper curve trends.

The SPI (McKee et al., 1993) was computed by taking into account the annual rainfall across the Tensift watershed over the entire period. It is mathematically expressed as follows:

$SPI = (P_i – P_m)/S$

P_i: Year's rainfall;

P_m: Average rainfall in the series on the timescale considered;

S: Standard deviation of the series on the timescale considered.

Impacts of drought events observed on water supply to the Takerkourst dam:

Both the temporal evolution of inflows in the Takerkoust dam and the volume of water allocated for irrigation were assessed in relation to drought events recorded in the Tensift watershed between 1985 and 2014.

3. RESULTS AND DISCUSSION

3.1 Analysis of precipitations variability

Variability over space:

The Tensift basin consists of mountainous areas of the High Atlas and the Haouz plains and is characterized by a relief that is very diverse, with contrasting altitudes. As such, there is a significant spatial variability between precipitations in the various climatic stations considered (Figure 2).

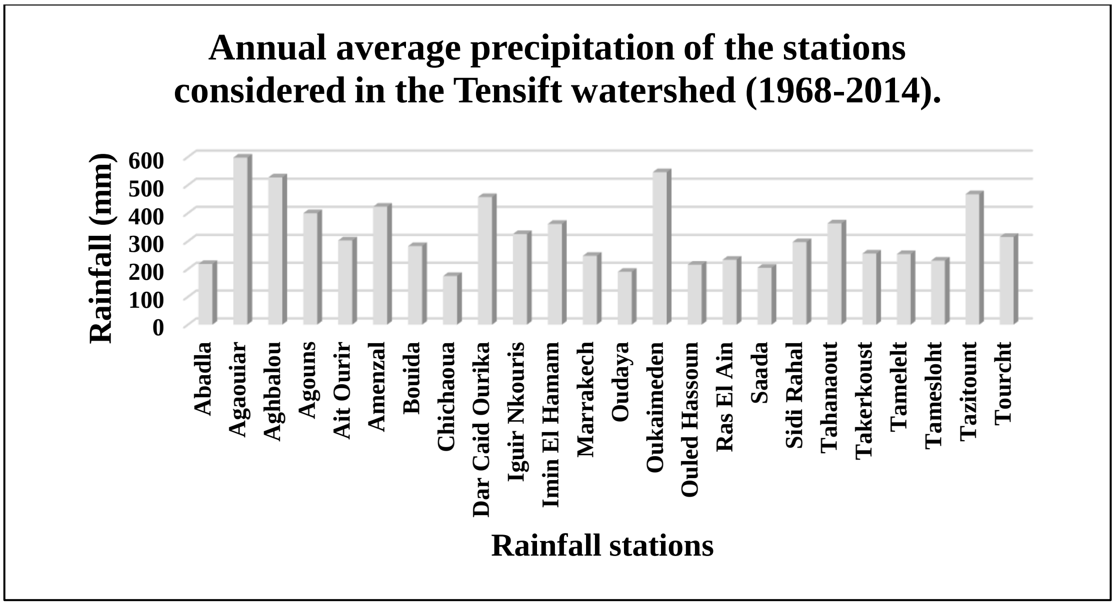

Figure 2. Annual average precipitation of the various stations considered in the Tensift watershed.

The highest rainfall was recorded in the highest altitude stations (Agaiouar, Oukaimeden, Aghbalou, Tazitount, Dar Caid Ourika, ...) while the lowest rainfall were recorded in lowland stations (Chichaoua, Oudaya, Abadla, Saada, ...). Rain increases with altitude.

A high spatial variability with regards to precipitation was observed in the Tensift watershed. This was characterized by Thiessen polygons within which precipitation was assumed uniform. Thus by applying the Thiessen polygons method, the following was obtained:

$$H_{EU} \text{ (mm)} = (S_1 * P_1 + S_2 * P_2 + \ldots + S_n P_n)/S_t = 250 \text{ mm}$$

Total average precipitation across the Tensift watershed over the period considered (1968-2014) was 250 mm.

Variability over time:

Annual precipitation means at the watershed scale was determined on the basis of weighted Thiessen polygons for the whole watershed using the precipitation data of the stations considered. The annual rainfall in the watershed of Tensift vary from one year to another. High temporal rainfall variability is observed in the watershed between 1968 and 2014.

The moving average was used to reduce or eliminate variations and to highlight the cyclical phenomena: wet and dry periods. Fifth order moving averages were calculated. Representation of annual rainfall on the same graph, moving averages and the average of total rainfall at the watershed scale helped to observe the evolution of rainfall in time and consequently in both wet and dry periods (Figure 3).

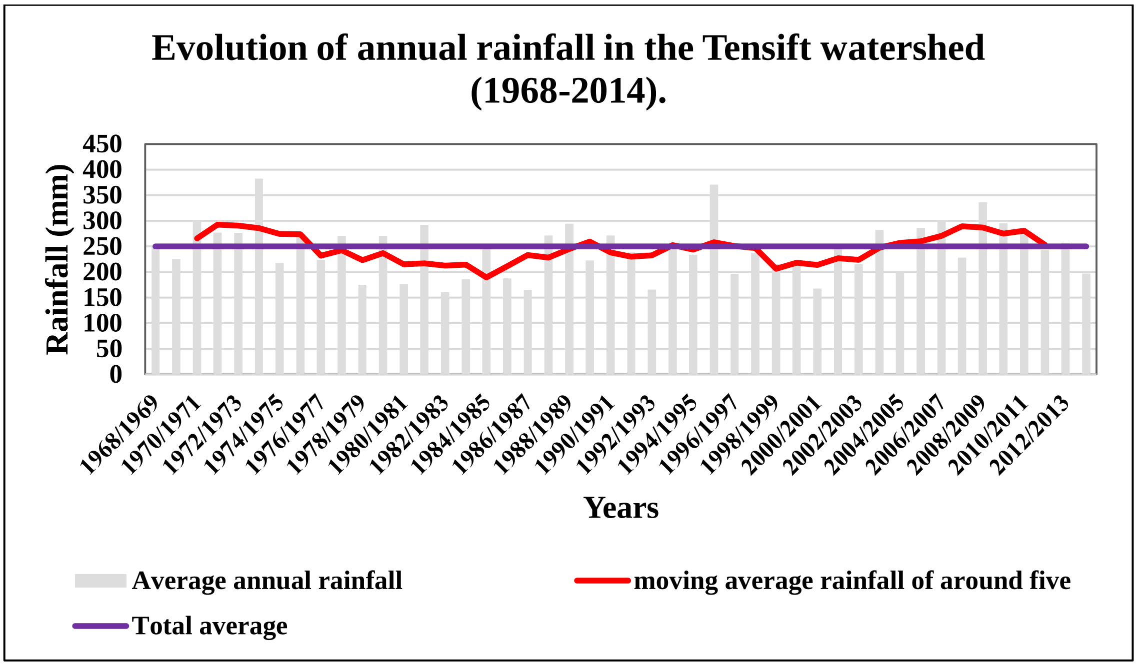

Figure 3. Evolution of annual rainfall in the Tensift watershed (1968-2014).

Precipitation in the Tensift watershed showed a wide variation between 1968 and 2014. Moreover, during this period, 1982/1983, 1986/1987, 1992/1993 and 2000/2001 were drier (P = 160.7, P = 164.7, P = 165.6 mm and P = 167.2 mm respectively), while the 1973/1974, 1995/1996 and 2008/2009 were wetter (P = 401.5 mm, P = 370.5 mm P = 366.0 and respectively). The total average rainfall in the basin during the period was 250 mm.
Alternating wet and dry periods was observed (Figure 3). The basin experienced, between 1968 and 2014, two rainy and three dry periods. Wet periods were between 1970-1977 and 2006-2012 whereas dry periods were between 1977 and 1990, 1990 and 1994, and 1997 and 2006. The Tensift watershed had experienced periods of repeated droughts in recent years, over a period of 28 years between 1977 and 2005.

3.2 Temporal analysis of drought events by SPI

SPI was calculated using annual average for the Tensift watershed (Figure 4).

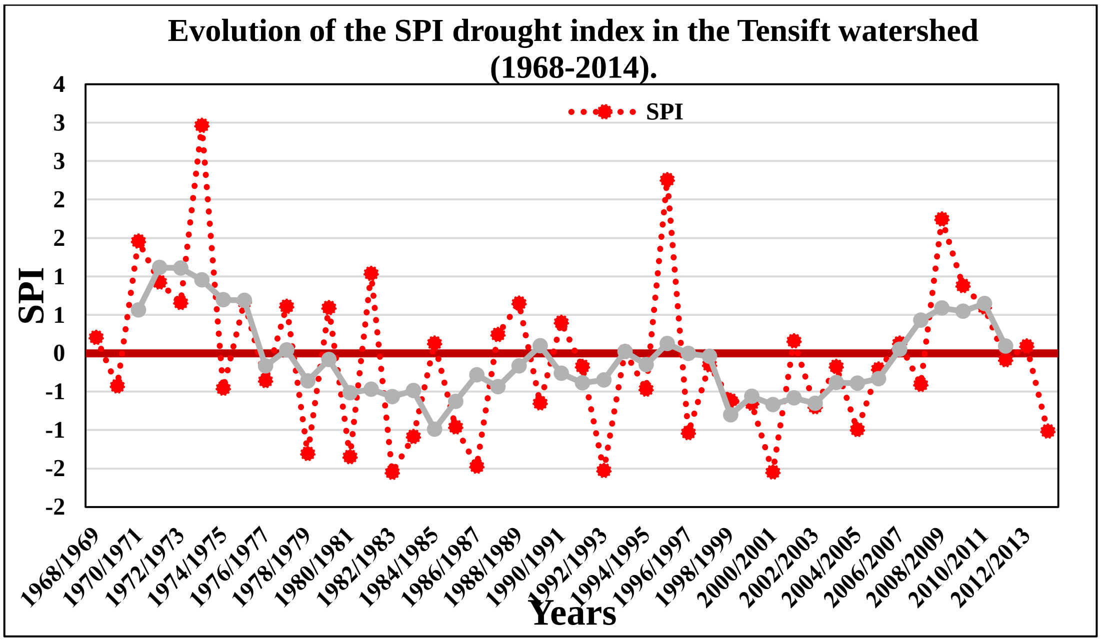

Figure 4. Evolution of the SPI drought index in the Tensift watershed (1968-2014)

The results obtained using SPI confirmed those obtained by graphical analysis. The basin experienced three dry periods, of which the most significant were between 1977 and 1990, 1997 and 2007, and the least significant between 1990 and 1994.
The general trend was that the Tensift watershed experienced the most significant wet periods between 1970 and 1978 before experiencing successive dry periods of varying intensities up until 2006/2007, from which there was return of rainfall, even though slightly lower than between 1970 and 1978. This lasted until 2012 after which a drop was observed.

3.3 Impacts of drought events observed on water supply to Takerkoust Dam

We observed fluctuations over time on the supply of water to Takerkoust dam. Supplies experienced two significant decline periods between 1985 and 2014 (Figure 5). The first one between 1990 and 1995, and the second between 1997 and 2008.

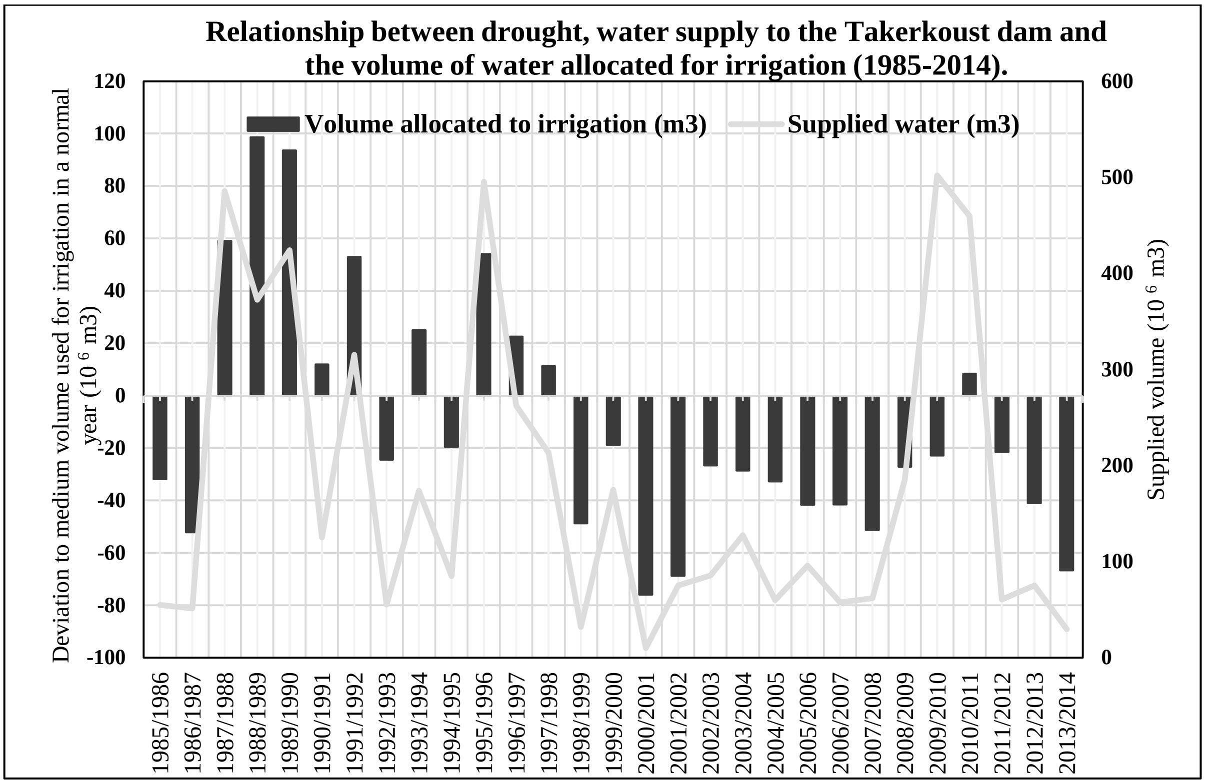

Figure 5. Relationship between drought, water supply to the Takerkoust dam and the volume of water allocated for irrigation (1985-2014).

The decline in water supplies to the dam was greater between 1997 and 2008 than between 1990 and 1995. Declining precipitation flows into the Takerkoust dam increased over time, with these periods corresponding to two periods of drought observed between 1985 and 2014. As such, the droughts experienced at the Tensift watershed (between 1990 and 1995 and 1997 and 2008) negatively impacted the water supplies to the Takerkoust dam.
This decrease in rainfall in the dam consequently impacted the volume of water allocated for irrigation, electric power generation and portable water. As such, the decrease in rainfall inputs linked to droughts resulted in a lower volume of water allocated for irrigation and increased water volume allocated to the production of portable water and electricity generation. The adopted strategy of resource allocation is to favor, in cases of drought, drinking water and production electricity over irrigation water.
The strategy adopted for the allocation of resources is to decrease, in case of drought, water allocated for irrigation. The irrigation schemes in the Tensift watershed, therefore, suffer from the effects of drought as limited water resources are allocated to them, which in turn leads to a decrease in irrigated area and consequently agricultural production.
There was a relation between water supply to the Takerkoust dam and the volume of water allocated for irrigation. A decrease in precipitation inputs causes a decrease in the volume of water allocated for irrigation and vice versa. However, some exceptions to this relationship have been observed over time. This is the case of the 1990-1991 growing season during which a significant volume was allocated to irrigation despite a decrease in inputs.

This could be explained by the fact that the three previous growing seasons (1987-1988, 1988-1989 and 1989-1990) were characterized by a high input of water, ensuring a stock of water in the dam. This made it possible to compensate for the 1990-1991 drought that led to the decrease in water inputs. The same thing was observed in the 1996-1997 and 1997-1998 seasons where the observed decrease was partially offset by significant contributions from the previous season (1995-1996).

There was a declined water resource for irrigation during the 2009-2010 campaign whiles there was an increase in rainfall inflows. This could be explained not only by the fact that this campaign was preceded by repeated drought years (resulting in a significant depletion of the stock of water in the dam), but also by seasonal drought manifested by both the lateness and absence, in some cases, of seasonal rainfall during the agricultural season.

4. CONCLUSION

Ecosystems of the Tensift watershed have suffered, in the course of their history, from major changes over time and space, and under the influence of several factors including human and environmental constraints, thus making them more vulnerable to climate change. The analysis of trend curves and the standardized precipitation index have both helped highlight the temporal evolution of drought sequences. The decrease in precipitation inputs linked to droughts resulted in a lower volume of water allocated for irrigation and vice versa.

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