Impact of meteorological drought on agriculture in the Tensift watershed of Morocco

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ABSTRACT

Located in the mid-west of Morocco, the Tensift watershed shelters the Takerkoust dam, which provides a part of the water used for irrigation of the N’Fis agricultural area, which is an important irrigated area of the Tensift watershed. This study deals with the impact of droughts on water inflows to the Takerkoust dam and how the water shortage caused by droughts affects agricultural production in the N’Fis area. The standardized precipitation index (SPI) was used to illustrate the temporal evolution of drought periods. The trend observed on data showed that the Tensift watershed experienced a succession of droughts and humid periods of varying intensities. Periods of drought have negatively affected water inflows to the Takerkoust dam, and therefore the amount of water allocated to agricultural irrigation. Years that experienced droughts showed a restriction of more than 50% of water volume planned for irrigation. During periods of water scarcity, farmers reduce or completely avoid irrigation of annual crops to save water for irrigation of perennial crops. The water shortage for irrigation has led in some cases to a drop of up to 100% of the surface allocated to the production of annual crops.

Key words | drought, irrigation, Morocco, SPI, Tensift watershed, water inflows

INTRODUCTION

In the Mediterranean region, rising temperature is consistent with the global climate change trend recognized by the scientific community (IPCC 2014), who estimated that the change in the average surface temperature of the Earth would exceed that of the 1850–1900 period by at least 1.5°C at the end of the current century. Observations of increasing minimum temperatures and occurrence of drought are well known in North Africa (Donat et al. 2013; Nouaceur et al. 2013). Likewise, Morocco will likely be exposed to an increase in temperature of 2.3–4.3°C and a decrease of 41% of precipitation by the end of the current century (World Bank 2013).

Water is the primary medium through which climate change affects the Earth’s ecosystem and people (United Nations World Water Assessment Program 2009). Drought affects the level of precipitation, groundwater storage, and the availability of soil moisture. It can lead to water shortages, affecting agricultural and hydro energy production, environmental quality, and human well-being (Hisdal & Tallaksen 2003). It can cause significant damage, affecting a large number of vulnerable populations (Wilhite 1993).

Drought is a particular risk to agricultural production and productivity (Bogardi et al. 1988; Bargaoui 1989; Bogardi & Duckstein 1993; Ardoin et al. 2003; Cudennec et al. 2007), mainly in arid and semi-arid regions. Droughts lead to water shortages and hence to a reduction of agricultural production and productivity. Mobilization of water resources for agricultural or other uses is largely possible through construction of dams (Boudjadja et al. 2003; Tazi Sadeq 2006). However, the supply of water to dams is dependent on precipitation. The filling rate of dams’ reservoirs and hence the
amount of water stored depends on the amount of rainfall by period.

Due to its geographical position and climate characteristics, Morocco has experienced droughts through history. The characteristics of the hydrological context of the country are, naturally, an annual irregularity and inter-annual variability of rainfall with heterogeneous distribution of precipitation. Rainfall is highly variable from one year to another and its intensity varies geographically, with an increasing gradient from the south-east of the country to the north-west. Approximately 50% of precipitation is concentrated in only 15% of the country’s territories (MEMEE 2000a). Due to the recurrence of droughts and the trend of reduced rainfall, water resources are expected to decline by around 10–15% by the year 2020 (MEMEE 2000b).

Drought is a natural phenomenon resulting from a stochastic deficiency or temporal distribution of precipitation. We can distinguish meteorological, hydrological, and agricultural droughts. Nevertheless, precipitation, groundwater level, and the availability of soil moisture are the most used variables. To attenuate the effects of droughts, we need to characterize them in terms of intensity and frequency of occurrence. This would help develop early drought warning systems (Kogan 2000) and analyze their risk (Hayes et al. 2004), and thus allow for better planning and preparedness.

The country has already experienced many drought events, with the frequency of occurrence increasing over time (World Bank 2013). Based on historical data of 30 years, this study has shown that the frequency of droughts that were one every five years before the 1990s became one every two years since that date. It concluded that Morocco experienced the occurrence of moderate droughts every three years, medium droughts every five years, and severe droughts every 15 years. These frequent and severe droughts have led to strong annual variations of water resources availability in Morocco.

This availability of water is variable depending on the level of water evaporation and the frequency of occurrence of droughts, two phenomena exacerbated in recent years by climate change. The water deficit reached more than 70% in some areas of the country during some drought periods. In addition to the recurrent droughts, a growing demand, resulting particularly from population growth and economic development, accentuated this trend. Morocco is one of the 20 countries most stressed in terms of water resources availability (World Resource Institute 2014).

Indeed, the availability of water resources in Morocco is experiencing strong annual variations and a downward trend in global per capita availability of water (MDCE 2016). This variability has negative influences, particularly on agriculture, a main pillar of the Moroccan economy contributing to more than 14.4% of the gross domestic product (MEF 2015). Moroccan agriculture is mainly rain-fed and very sensitive to changes in precipitations (Jlibene & Balaghi 2009) and, by consequence, on the national economy, in general, which is positively correlated to agricultural production (MEF 2015b). With 85% of non-irrigated agriculture (MAPM 2012), the yield of major crops suffers very significant variations due to the variability of precipitations and the high frequency of droughts.

Climate change would create important impacts on the agriculture sector through considerable loss of crop yields, leading to negative consequences on food security and safety. Yet, that agriculture is highly dependent on water availability, which is becoming scarce, and it faces growing competition for water from other sectors of the economy. The social and economic losses associated with drought are prone to increase annually as the climate changes.

The Tensift watershed experiences a climate characterized by aridity with varying intensity, depending on altitude and, to a lesser extent, on continentality (Riad 2003). Precipitation is highly seasonal, generally irregular, and temporarily intense. Rainy periods occur normally during fall and winter. The dry season is often extreme, especially in lowland areas where temperatures and evaporation rates are high, mainly during drought periods.

This research deals with the assessment of drought periods on the Tensift basin and how they affect water allocation to agricultural production and other uses in the N’Fis sub-basin fed by water coming from Tkerkoust dam reservoir.

Several drought-monitoring indexes have been developed and used. Among these, we can mention the Palmer Drought Severity Index (PDSI) (Palmer 1965), Standardized Precipitation Index (SPI) (McKee et al. 1993), Rainfall Anomaly Index (Jones & Hulme 1996), Reconnaissance Drought Index (TDI) (Tsakiris et al. 2007), Perpendicular
Drought Index (Ghulam et al. 2007), and Standardized Runoff Index (SRI) (Shukla & Wood 2008).

The SPI has been used to assess dry events over a period of 47 years (1968–2015), due to the availability of only rainfall data in the study area. SPI was used to characterize precipitation deficits for a given period (McKee et al. 1993). It is the most widely adopted precipitation index (Wu et al. 2006; Naresh Kumar et al. 2009). SPI takes into account the variability of the rain for defined periods. It was calculated by fitting the precipitation data to a probability graph (McKee et al. 1993). It reflects the impact of drought on the availability of various water resources, and can be used for comparison over space and time (Wu et al. 2006). Due to its robustness, it has been widely used to study drought in various parts of the world, e.g., Canada (Quiring & Papakryiakou 2003), China (Wu et al. 2001), East Africa (Ntale & Gan 2003), Greece (Tsakiris & Vangelis 2004), and USA (Edwards & McKee 1997; Ji & Peters 2003).

The analysis carried out in this research concerns the evolution of precipitation in the river basin of Tansift in order to characterize the frequency of dry periods, as well as its impact on the water inflows to Takerkoust dam. The impact of drought events observed on the quantity of water allocated to irrigation of major agricultural crops in the N’fis irrigated area has been assessed.

MATERIALS AND METHODS

Presentation of the study area

The Tensift river basin covers an area of approximately 20,450 km², located between latitudes 32° 10’ and 30° 50’ north, and longitudes 9° 25’ and 7° 12’ west (Figure 1). It is located in the northwestern side of the High Atlas (HA) Mountains with a WSW–ENE orientation, which extends over a length of 900 km and an average width of 80 km (Amrhar 1995). These mountains constitute a barrier between the region and the Sahara in the south. Its overall morphology presents three sections: the eastern HA, the central HA and the western HA.

Indeed, the basin is bounded from the south by the HA Mountains ridgeline and to the north by a hilly area called Jbilet. To the east, it is bounded by the slightly marked drainage divide line, separating the Tensift basin from that of Tessaout, a tributary of the wadi Oum Er-Rbia and to the west by the Atlantic Ocean where the outlet is located. The watershed elevation ranges from 0 m at its outlet to 4,167 m at Toubkal. The basin is composed of two parts, the HA Mountains and the semi-arid central Haouz plain (HP).

The rainfall in the basin is low and characterized by a high spatial and temporal variability. The average annual rainfall is around 250 mm in Marrakech and can reach 700 mm on the peaks of the Atlas Mountains. Mean annual water availability is nearly 820 million m³, with a minimum of 70 million m³ and a maximum of around 2,500 million m³.

Three large dams (Takerkoust (70 Mm³), Wirgane (72 Mm³), and Tasekourt (24 Mm³)) provide water for irrigation, drinking, and hydroelectricity. A large inter-basin transfer scheme also brings in water (300 Mm³) from the Oum Er-Rbia basin to supply drinking water to the city of Marrakech (260 Mm³) and irrigation supply for the central HP (40 Mm³). There are also small dams providing water for irrigation as well as boreholes and springs. The abstracted groundwater is overharvested and suffers from an annual deficit, defined as the difference between net withdrawals and recharge, estimated to 100–150 million m³.

Takerkoust dam, located about 35 km south-west of Marrakech is the oldest dam in the watershed. It was constructed on the N’fis River, a tributary of the Tensift River, between the years 1929 and 1935. The dam aims to provide water for both agricultural irrigation and electricity production. The Haouz irrigated area is divided into three main parts: Central Haouz, Tessaout upstream, and Tessaout downstream. The N’Fis irrigated area (Figure 1) is a part of the Central Haouz. It extends over a surface of 21,200 ha and is supplied, partially, by water for irrigation by Takerkoust dam.

Data

The Tensift river basin is composed of two contrasting zones in terms of both rainfall and hydrological points of view: the HP and the HA Mountains. Ten rainfall stations, including seven located in the HP and three located in the Tensift HA, were considered for data analysis (Figure 1). The stations
possess long time series (1968–2015) of rainfall records, with no missing points. Of the ten stations, only the Marrakech station has temperature data, which does not allow us to use a more elaborate drought index such as the PDSI.

Data for water supply to the Takerkoust dam were limited to only the period 1985–2014 for which records were available. For water allocated to the N’Fis irrigated area, the data available used correspond to the period 2002–2014. The Agricultural Development Office of Haouz (ORMVAH) provided both sets of data.

Methodology

Analysis of drought events in the Tensift watershed

The spatiotemporal evolution of drought at each station in both the HP and the Tensift HA was assessed using the SPI. The SPI has advantages in terms of statistical consistency and the ability to describe both short- and long-term impacts of drought across different time scales (McKee et al. 1993).

The method for calculating SPI has been described in detail by several authors (McKee et al. 1993, 1995; Edwards & McKee 1997; Guttman 1998). It involves the processing of the precipitation time series in a standardized normal distribution with a zero mean and unitary standard deviation, also referred to as normal distribution. This is obtained by adjusting an appropriate probability density of the frequency distribution of precipitation averaged over a defined time scale. Different time scales were considered for the calculation of SPI: 3 months (SPI-3), six months (SPI-6), 9 months (SPI-9), and 12 months (SPI-12). In this study, SPI was calculated using DrinC software (Tigkas et al. 2014).

According to the World Meteorological Organization (World Meteorological Organization 2012), SPI-3 provides an indication of moisture conditions for both short and medium terms, as well as estimated rainfall over a season. In predominantly agricultural areas, SPI-3 can be more
efficient than the slow response Palmer Index (Palmer 1965) or other current hydrological indices used to highlight the nature of ongoing moisture conditions.

SPI-6, on the other hand, provides an indication of trends in precipitation over a season, up to a medium term. For this time scale, it presents even more sensitivity to the conditions than the Palmer index. SPI-6 can be very efficient in highlighting precipitation in specific seasons.

SPI-9 provides an indication of the inter-seasonal rainfall regimes, in the medium term. It is only after nine months that we can establish the link between short- and long-term seasonal droughts capable of becoming a hydrological drought or a drought lasting several years.

SPI for the 12 months’ time scale is usually associated with river flows, dams’ reservoirs levels, and groundwater levels relatively in the long term. This index also distinguishes dry years from humid ones or deficit years from surplus ones. Drought begins when the SPI is consecutively negative and its value reaches an intensity of $-1$ or lower. Drought ends when the SPI becomes positive. Negative values indicate an annual drought compared to the reference period chosen whereas positive values indicate humid periods (Table 1).

### Trend test and abrupt change analysis

The non-parametric Mann–Kendall test (Kendall 1975) is commonly used to detect monotonic trends in time series of hydrologic variables. However, the results of the test may contain an error if significant autocorrelation exists in the data series. To avoid this problem, a pre-whitening procedure will be performed to remove the autocorrelation in the time series. Therefore, autocorrelation coefficient should be calculated to identify the existence of significant autocorrelation within time series and to perform a pre-whitening procedure. The pre-whitening procedure and Mann–Kendall trend test have been performed using RStudio.

The Mann–Kendall test statistic is calculated according to:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(X_j - X_k)$$

with

$$\text{sgn}(x) = \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases}$$

The mean of $S$ is $E[S] = 0$ and the variance $\sigma^2$ is:

$$\sigma^2 = \frac{1}{18} \left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5) \right\}$$

where $p$ is the number of the tied groups in the data set and $t_j$ is the number of data points in the $j$th tied group.

The statistic $S$ is approximately normal distributed and the following $Z$-transformation is used:

$$Z = \begin{cases} \frac{S - 1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S + 1}{\sigma} & \text{if } S < 0 \end{cases}$$

The $Z$-statistic obtained from the test will reflect the trend of a time series, while a positive value of $Z$ represents an upward trend, and vice versa (Li et al. 2019). The $Z$-statistic also indicates the significance of trend in a time series. The change rate could be estimated via the Sen’s slope (Sen 1968).

Pettitt’s and Buishand range tests have been used to detect the change points in rainfall data time series.

Pettitt’s test is based on the rank $r_i$ of the $y_i$ ($i$ is the year from 1 to $n$) of the series:

$$X_y = 2 \sum_{i=0}^{y} r_i - y(n + 1), \quad y = 1, 2, \ldots, n$$

### Table 1: Classification of droughts according to the SPI (Cheikh et al. 2015)

<table>
<thead>
<tr>
<th>SPI classes</th>
<th>Drought severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2+</td>
<td>Extremely wet</td>
</tr>
<tr>
<td>1 to 2</td>
<td>Very wet</td>
</tr>
<tr>
<td>0 to 1</td>
<td>Moderately wet</td>
</tr>
<tr>
<td>-1 to 0</td>
<td>Moderately dry</td>
</tr>
<tr>
<td>-2 to -1</td>
<td>Severely dry</td>
</tr>
<tr>
<td>-2 and less</td>
<td>Extremely dry</td>
</tr>
</tbody>
</table>
The break occurs in the year \( k \) when

\[
X_k = \max_{1 \leq i \leq n} |X_i|
\]

Pettitt then compares the value with the critical value (1979).

For Buishand range test, the adjusted partial sum is defined as:

\[
S_0 = 0 \quad \text{and} \quad S_y = \sum_{i=1}^{y} (Y_i - \bar{Y}), \quad y = 1, 2, \ldots, n
\]

When the series is homogeneous, then the value of \( S_y \) will rise and fall around zero. The break occurs in the year \( y \) when \( S_y \) has reached a maximum or minimum. Rescaled adjusted range, \( R \), is obtained by

\[
R = \frac{\max S_y - \min S_y}{s}
\]

The \( R/\sqrt{n} \) is then compared with the critical values given by Buishand (1982).

**RESULTS AND DISCUSSION**

**Evolution of rainfall over time and space**

The mean annual rainfall was of significant variability over time and space (Figure 2). It varied from one year to another, presenting higher values in the Tensift HA (Aghbalou, Ourika Tahanout) than in the HP (Marrakech, Oudaya, Saada, etc.). This was probably due to the effect of altitude. Indeed, the mean annual rainfall in both the HP and Tensift HA was approximately 300 mm and 500 mm, respectively, thus confirming the HP belonging to the arid zone. The Tensift High Atlas, on the other hand, was characterized by a climate varying from semi-arid to humid.

The analysis of mean monthly rainfall highlighted a rainy season between October and May, and a dry one between June and September (Figure 3). The most humid season corresponded to the period between January and

![Figure 2](http://iwaponline.com/jwcc/article-pdf/11/4/1323/829512/jwc0111323.pdf)

**Impact of drought events observed on water supply inflows to the dam and on water allocation for irrigation**

The impact of drought on the volumes of water inflows to the dam’s reservoir was analyzed graphically during the period 1985–2014. Data for both planned and real volumes of water allocated to major crops in the N’fis area from Takerkoust dam were only available for the 2002–2014 period. The impact of droughts on the allocation of water for irrigation of major crops (vegetables, fodder, cereals, legumes, and arboriculture) was assessed for this period.
April while the driest period to the period between June and August. Average precipitation was higher in the Tensift HA than in the HP.

Table 2 | Evolution of dry and humid periods observed in Tensift watershed (1968–2015)

<table>
<thead>
<tr>
<th>Periods</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968–1978</td>
<td>Large number of rainfall events indicating high humidity</td>
</tr>
<tr>
<td>1978–1993</td>
<td>Succession of dry periods characterized by moderate, severe and extremely severe droughts</td>
</tr>
<tr>
<td>1993–1998</td>
<td>Wet period</td>
</tr>
<tr>
<td>1998–2008</td>
<td>Succession of dry periods characterized by moderate, severe and extremely severe droughts</td>
</tr>
<tr>
<td>2008–2011</td>
<td>Wet period</td>
</tr>
<tr>
<td>2011–2014</td>
<td>Dry period</td>
</tr>
</tbody>
</table>

SPI

In order to characterize the level of severity of droughts observed, we calculated the SPI for seven stations from the HP and three stations from the Tensift HA, during the period 1968–2015. The evolution of SPI in both areas (Table 2; Figures 4–6) showed that the two zones experienced identical drought events but with varying intensities.

Analysis of descriptive parameters of drought events

Intensity of drought events

For the analyzed 47 year period (Table 3), the most significant drought intensities were those observed in 2001–2002 at a seasonal scale, and in 2006–2007 at annual scale, in the HP. In the Tensift HA, the most remarkable droughts in terms of intensity were those of the years 1981–1982 and 1992–1993 at seasonal and annual scales, respectively. The dry periods were characterized by extremely severe droughts in terms of intensity. Both the HP and the Tensift HA were severely affected by drought, irrespective of the time scale considered.

Duration of drought events

The analysis of drought duration showed that they varied from one time scale to another (Table 4). At a seasonal
Figure 5 | SPI of the Tensift High Atlas stations (1968–2015).

Figure 6 | SPI for both the Haouz plain and the Tensift High Atlas (1968–2015).

Table 3 | Intensity of drought events recorded during the period 1968–2015 at different time scales

<table>
<thead>
<tr>
<th>Time scale</th>
<th>Parameter</th>
<th>Haouz Plain</th>
<th>Tensift High Atlas</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 months (SPI-3 months)</td>
<td>Intensity (SPI)</td>
<td>−2.33</td>
<td>−2.03</td>
</tr>
<tr>
<td></td>
<td>Type</td>
<td>Extremely severe</td>
<td>Extremely severe</td>
</tr>
<tr>
<td>6 months (SPI-6 months)</td>
<td>Intensity (SPI)</td>
<td>−1.98</td>
<td>−2.41</td>
</tr>
<tr>
<td></td>
<td>Type</td>
<td>Severe</td>
<td>Extremely severe</td>
</tr>
<tr>
<td>9 months (SPI-9 months)</td>
<td>Intensity (SPI)</td>
<td>−2.08</td>
<td>−1.99</td>
</tr>
<tr>
<td></td>
<td>Type</td>
<td>Extremely severe</td>
<td>Severe</td>
</tr>
<tr>
<td>12 months (SPI-12 months)</td>
<td>Intensity (SPI)</td>
<td>−2.07</td>
<td>−2.12</td>
</tr>
<tr>
<td></td>
<td>Type</td>
<td>Extremely severe</td>
<td>Extremely severe</td>
</tr>
</tbody>
</table>
scale, the longest drought lasted about ten years, and was of moderate intensity in both the HP and the Tensift HA. At an annual scale, the duration was about 15 years in both areas of the watershed. However, drought remained moderate in the Tensift HA whereas the HP experienced a severe one. Regardless, there seemed to be a trend towards increasing severity of drought events in the plain.

**Frequency of drought events**

The analysis of historical data over 47 years revealed the occurrence of a drought every two years irrespective of the time scale considered. In the HP, at both seasonal and annual scales, there were two moderate droughts every three years, a severe drought every five years, and two extremely severe droughts every 25 years (Figure 7).

In the Tensift HA, at seasonal scale, there were two moderate droughts every three years, three severe droughts every ten years, and a year of extremely severe drought every 25 years. At an annual time scale, there were three moderate droughts every four years, three severe droughts every 20 years, and two extremely severe droughts every 25 (Figure 8).

The analysis of frequency and intensity of drought showed that both the HP and the Tensift HA were similarly affected by drought, irrespective of the time scale considered. However, the HP seemed to be more affected by moderate to extremely severe drought, at seasonal scale, and by severe to extremely severe drought at an annual scale. The Tensift HA, on the other hand, seemed to be affected by severe and moderate droughts at seasonal and annual scales, respectively. The HP was subject to long-term severe to very severe droughts while the Tensift HA was subject to moderate drought.

**Trend test and abrupt change analysis**

The tests of Pettitt and Buishand range detected one abrupt change point year at 1977 for both HP and HA annual rainfall. The average annual precipitation of the reference period (1968–2015) was 267.9 and 417.4 mm, for HP and the HA,

<table>
<thead>
<tr>
<th>Time scale</th>
<th>Haouz Plain</th>
<th>Tensift High Atlas</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 months (SPI-3 months)</td>
<td>10 Moderate</td>
<td>8 Moderate</td>
</tr>
<tr>
<td>6 months (SPI-6 months)</td>
<td>10 Moderate</td>
<td>9 Moderate</td>
</tr>
<tr>
<td>9 months (SPI-9 months)</td>
<td>15 Severe</td>
<td>16 Moderate</td>
</tr>
<tr>
<td>12 months (SPI-12 months)</td>
<td>15 Severe</td>
<td>15 Moderate</td>
</tr>
</tbody>
</table>

**Table 4** Duration in years of drought events recorded during the period 1968–2015 at different time scales

Figure 7 | Frequency of drought periods (SPI-3 months, SPI-6 months, SPI-9 months, SPI-12 months) in the Haouz plain (1968–2015).
respectively. The reference period can be split up into two periods, different in the mean: 1968–1977 with a mean annual rainfall of 343.9 and 565.7 mm, and 1978–2015 with a mean of 247.4 and 377.3 mm, respectively, for the HP and the HA.

The annual time series of the rainfall data for the period of 1968–2015 was analyzed via the pre-whitening procedure and Mann–Kendall trend test. During 1968–1977, the average annual precipitation was 343.9 and 565.7 mm with a downward slope of −10.98 and −7.66 mm/year, respectively, in the HP and the HA, but the change trends were not statistically significant. During 1978–2015, the average annual precipitation was 247.4 and 377.3 mm with an increasing slope of 0.22 mm/year and a downward slope of −0.26 mm/year, respectively, in the HP and the HA, but the change trend was not statistically significant.

During the last decade prior to 1977, the average annual precipitation decreased greatly (slope of −10.98 and −7.66 mm/year, respectively, for HP and HA), whereas after 1977, the annual average is more or less stable (slope of 0.22 and −0.26 mm/year, respectively, for HP and HA). Over the period 1968–1977, the total annual rainfall was above normal while over the period 1978–2014, the rainfall is below normal rainfall. The break can be the result of the installation of new recording equipment, altering the position of the equipment, or a shift in the climate. This cannot be clearly stated due to the lack of information concerning the recording equipment.

Impacts of drought events observed on water inflow to Takerkoust dam, and on the volume of water allocated to irrigation

The SPI-12 months during the 1985–2014 period is provided by Figure 9. This period corresponds to the era for which data on water inflows to the dam and volume of water allocated to irrigation were available.

Fluctuations of water inflow to the dam’s reservoir were observed over time. Indeed, the dam experienced two significant water shortage inflow periods between 1985 and 2014. The first one occurred between 1990 and 1995, and the second one between 1997 and 2008 (Figure 9).

Water inflow to the Takerkoust dam was correlated to the levels of precipitation, with the decline in inflows observed over time (1990–1995 and 1997–2008) corresponding to periods of drought.

As part of the hydro-agricultural development model, two main stakeholders are involved in the planning, development, and management of water resources for irrigation in the basin. They are the River Basin Agency of Tensift (ABHT), which is responsible for water resources management at the watershed level and the ORMVH, responsible for the development and management of agricultural irrigation systems.

Planning and preparing programs for irrigation involves making predictions according to two possible scenarios, sufficient water storage in the dam’s reservoir and insufficient water availability. At the beginning of each year, ABHT
establishes hydrological forecasts of annual water inflows to the Takerkoust dam reservoir. The water allocation program bases its distribution on the needs of agricultural and hydro-power productions and of potable water. Allocations are then made on the basis of the water available in dams at the beginning of the year (September); forecasted inflows with respect to different assumptions of occurrence; losses through evaporation and leakage; and the reserve to keep at the end of year to ensure the start of the following agricultural year (late August).

The irrigation program corresponding to irrigated areas in the large agricultural perimeters is primarily dependent on the volume of water available in dams’ reservoirs, and on the expected precipitation during the year. Consultation meetings with ABHT, the National Office of Water and Electricity (ONEE), ORMVAH, as well as other important water users are held at the beginning of each agricultural year. The partners define, in mutual agreements, the quantity of water to allocate to agricultural irrigation. Once the volumes are known, ORMVAH establishes a plan of using the given water allocation volume.

Irrigation programs agreed upon at the beginning of each agricultural year are normally revised, when needed, depending on changes in the water inflows into Takerkoust dam’s reservoir. In periods of drought, water supply from the dam cannot meet all agricultural needs. In these cases, a ‘reduced’ program is selected from several potential scenarios of rainfall.

Figure 10 shows the relationship between annual inflows to the dam and the annual volume of water allocated to irrigation. Data on water inflows to the Takerkoust dam and on amount of water allocated to irrigation, according to a chosen allocation scenario during each crop year between 1985 and 2014, were provided by ORMVAH.

The decrease in water inflows to the Takerkoust dam was greater between 1997 and 2008 than between 1990 and 1995. Declining flows into Takerkoust dam increased over time, with these periods corresponding to two events of drought observed between 1985 and 2014. The droughts experienced at the Tensift river basin (between 1990 and 1995, and 1997 and 2008) greatly affected the water inflow to the Takerkoust dam. The decrease in precipitation, and consequently inflows to the dam, negatively affected the volume of water allocated to irrigation, electric power generation, and potable water. The strategy adopted for water resources allocation during years of droughts is to decrease the quantity allocated to irrigation. Consequently, the irrigated agriculture in the N’Fis area will benefit with only limited volume of water for irrigation. This restriction results in a reduction of the surface of land being exploited for agriculture.

There was a relationship between water inflows to the Takerkoust dam and the volume of water allocated to irrigation. However, some exceptions to this relationship have been observed over time. This was the case of the 1990–1991 agricultural season, during which a significant...
The volume of water was allocated to irrigation despite a decline in water inflow to the dam reservoir. This could be explained by the fact that the three previous years (1987–1988, 1988–1989, and 1989–1990) were characterized by a high inflow of water into the dam, ensuring significant stock of water in the reservoir. As a result, it was possible to compensate for the 1990–1991 droughts that led to the decrease in water inflows. The same situation was observed in the 1996–1997 and 1997–1998 seasons where the shortage of inflows was partially offset by significant contributions from the previous season (1995–1996).

The declining allocation of volume of water for irrigation during the 2009–2010 campaign, when there was an increase in rainfall, could be explained by the fact that this campaign was preceded by repeated drought periods resulting in a significant depletion of the stock of water in the dam’s reservoir. It could also be explained by the seasonal drought manifested by both tardiness and/or absence, in some cases, of seasonal rainfall during the agricultural year.

**Impacts of drought events observed on the expected volume and the volume actually allocated to irrigation of major agricultural crops in the N’fis irrigation scheme**

The N’Fis irrigated area is located in the HP, and is mainly supplied in water for irrigation by the Takerkoust dam. Impacts of drought observed during 2002–2014 on major crops of the N’fis irrigated area were analyzed. Figure 11 shows the evolution of SPI-12 months during this period, and data of both planned and real volumes of water allocated for irrigation of major crops in the N’fis irrigated area. The planned volume of water was not always the real volume allocated due to drought events.

At the beginning of each agricultural year, a forecast of the volume of water to allocate for irrigation is performed. Several scenarios are envisioned for revising this forecast based on the level of precipitation (depending on drought occurrence) by ABHT and ORMVAH, in partnership with other water users. Various revisions could take place during one year depending on the amount, timing, and distribution of rainfall. The 2002–2014 time period experienced two events of drought (2002–2008 and 2012–2014) and one rainy event (2008–2012).

There was a significant restriction in the volume of water allocated to irrigation of major crops during dry periods (Figures 12 and 13). Indeed, during periods of drought, restrictions on volume of water planned for irrigation increased from 39 to 58%. This confirmed the impact of drought on water inflow to the Takerkoust dam, and thus the volume of water allocated to major crops in the N’fis irrigated area. Taking into consideration the 2004–2005 agricultural years which experienced drought, the...
measures taken were revised with respect to multiple scenarios, and the figures retained are detailed in Figure 14.

The graph shows the impact of drought on some major crops in the N’fis irrigated area. The agricultural years which experienced drought (2004–2005) showed a restriction in water allocation of 63% and 58% of total expected and planned areas for irrigation, respectively, while there was no restriction in the year in which there had been moderate water availability (e.g., 2010–2011).

Dry periods resulted in greater restrictions in volumes of water allocated to irrigation, significant reduction in irrigated area, and consequently, a decline in agricultural production. Restrictions occur when there is drought and are implemented by the ABHT and ORMVAH, in collaboration with the other water users, depending on the importance of the level of water storage in the dam.

For instance, cereals, which are Morocco’s main agricultural product, experienced 100% decrease in the cultivated area during the 2004–2005 agricultural year. In fact, both cereals and vegetable crops were abandoned and/or not
irrigated entirely (100% of restriction of their areas) due to drought observed during 2004–2005 in the N’fis irrigation scheme. However, during the 2010–2011 period, characterized by the absence of drought, cereal cultures were not affected. Additionally, the expected area to be irrigated for fodders experienced 50% restriction, while arboriculture areas were not touched.

The strategy adopted by farmers to cope with these restrictions which occur during drought periods is to limit irrigation or abandon it entirely for annual crops like cereals, vegetables, and fodder crops, while focusing on perennials such as orchards. This could be explained by the fact that they could abandon annual crops due to drought, but the damage would be too significant not to irrigate trees cultivated for many years and allow them to die because of the drought.

The irrigated cereal, fodder, and vegetable crops are highly vulnerable to drought in the irrigated area of N’fis, in both modern and traditional irrigation schemes. In addition to the currently adopted strategy to deal with the restrictions, farmers must think about developing crop varieties which are resistant to drought and require a small amount of water for great production.

**CONCLUSION**

This study deals with the impact of meteorological droughts assessed by the SPI on water inflows to the Takerkoust dam, and how the water shortage caused by droughts affects agricultural production in the N’fis area.

The abrupt change point in 1977 was detected for the annual rainfall series by Pettitt and Buishand range tests. The pre-whitening procedure and Mann–Kendall trend test found a non-significant downward trend of average annual precipitation with a slope of $-10.98$ mm/year and an increasing slope of $0.22$ mm/year for the period of 1968–1977 and 1978–2015 in the HP. Analysis of the SPI has allowed highlighting the temporal evolution of drought sequences in the River basin of Tensift. The trend observed on data showed that the Tensift watershed experienced a succession of droughts (1975–1995, 1999–2008, 2012–2014) and humid periods (1968–1975, 1995–1997, 2009–2011) of varying intensities. The most significant droughts were those observed in 2001–2002 at a seasonal scale, and in 2006–2007 at annual scale, in the HP. The dry periods were characterized by extremely severe droughts in terms of intensity. At a seasonal scale, the longest drought lasted about ten years and at an annual scale, the duration was about 15 years. There was occurrence of drought every two years, irrespective of the time scale considered.

Drought years experienced during the analyzed period have negatively affected water inflow to the Takerkoust dam, and consequently, the supply of water for irrigation. A decrease in precipitation led to a reduction of water supply, and consequently, led to a reduction of the volume of water allocated to irrigation.

In situations like this, farmers adopt practices based on reducing the amount of water for irrigation of annual crops in order to save water for perennial ones. Indeed, drought periods have led to a reduction of more than 50% of the potential irrigated area in some years. In some other years, drought has resulted in a complete restriction of irrigation for annual crops such as cereals and vegetables. Even though farmers are not always happy with these restrictions, it appears to be an acceptable and adaptive policy for water management.

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