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Assessment of Climate Variability and Agricultural Activities in the Area of Tadla Plain

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Abstract

The variations in both precipitation and temperature have far-reaching effects on agricultural activities and the accessibility of water resources. These climatic parameters are pivotal in determining the availability of both groundwater and surface water for agricultural use. The aim of this study was to evaluate the variations in climate parameters, focusing on precipitation and temperature, alongside changes in cultivated land area and crop yields in the Tadla area (Béni Mellal Khénifra region, Morocco); additionally, our research looks at the changes in water inflow into two dams and four aquifers. Trends were assessed over the period of 2010-2020 using the standardized precipitation index (SPI) method, as well as the parametric regression method and nonparametric Mann-Kendall and Sen's slope test. This analysis can be a preliminary step in demonstrating the effects of climate variability on water resource availability and its adverse impacts on agriculture in the region. The results showed a decreasing trend for some yield crops despite the increase in the cultivated area. The results of the groundwater levels and inflow dams showed a significant upward evolution. The analysis of the obtained SPI values and temperatures has revealed a notable and consistent upward trendencies. This upward trajectory indicates that both the SPI values, which reflect precipitation patterns and the temperatures, have been on the rise over the examined period. These results prompt reflection on the effects of climate variability on water resources in the region and economic activities, particularly agriculture.

Keywords

Béni Mellal Khénifra Region, Groundwater, Mann Kendal Method, Regression Groundwater Levels, Standardized Precipitation Index

1. Introduction

Climate change and variability have concerned scientists and policy makers for decades because of their damaging effects on ecosystems and human activities. This risk is amplified by the climatic disturbance that the planet as a whole is experiencing. Climate change consequences on water resources are strong and affect many sectors such as agriculture (Park et al., 2012).

In fact, global climate change is reflected locally through a number of changes that are altering the conditions of production. 1) It is a question of shifts in the climatic calendar such as delayed rainfalls; 2) Also changes in annual water levels with more frequent and/or severe droughts in many areas; 3) The increased frequency of unusual events such as (cyclones, hailstorms; 4) Finally, a strong temporal and spatial variability at the local level.

Morocco, which is considered an arid or semi-arid country, remains one of the most vulnerable countries to the effects of climate change. Several studies on rainfall in Morocco have shown that the number of rainfall deficit annex is greater than the number of surplus annexes, with an overall downward trend of about 23% (Sinan et al., 2009). As for temperatures, studies have shown an increasing trend of warmth ranging from 0.3 degrees to 2.5 degrees depending on the regions (Babqiqi, 2014).

Climate change has wide-ranging consequences, particularly evident in the agricultural sector, which plays a pivotal role in global food production and the economy. Furthermore, the anticipated global population surge to 9.7 billion by 2050 intensifies the strain on agricultural lands to meet escalating food demands, compounded by climate change's adverse effects. Given the inseparable connection between climate change and agriculture, rapid and erratic shifts in climatic conditions pose a grave threat to global food security on an unprecedented scale (Arora, 2019).

The impact on agriculture is various. It not only weighs on people, on the capital of farms and on the results of the latter (less productive crop and Animal husbandry systems), but also on collective dynamics, all of which contribute to increasing the vulnerability of the poor. Declining crop and livestock yields, the impossibility of using traditional risk management mechanisms besides doubt break down systems and lead to short term strategies that are often damaging to the environment and even to the economic sustainability of farms. Frequent and severe droughts, largely driven by climate change, worsen crop productivity by immobilizing nutrients and accumulating salt in soils, rendering them parched, unfit for growth, saline, and ultimately infertile. Over time, these desolate lands become unsuitable for cultivation and are eventually forsaken by farmers, resulting in economic losses and social challenges.

In the Béni Mellal–Khenifra region, the economic activity is mainly centered on the agricultural sector. It is one of the main agricultural regions of the country. The region is characterized by a practical agricultural area of 959.000 hectare that is about 11% of the national agricultural area. 206.000 Hectare of which is irrigated (that is 22% of the region's agricultural area and 15% of the irrigated area in Morocco (CRBK, 2019).

Climate change is reflected in the Béni-Mellal–Khenifra region in various ways: increasing temperatures and irregular rainfall, frequency and duration of droughts. These events have a significant impact on agriculture, which leads to a decrease in agricultural production and livestock. The Climate change affects agricultural water needs, water availability and quality (Eddoughri et al., 2022).

The Tadla plain is part of the Béni Mellal-Khenifra region, which extends over an area of 3600 hectares and is crossed by the Oum Rbia River. The useful agricultural surface represents 80% and the rest is in the form of range and uncultivated land 17% and forests 3%. The irrigated area represents 38% of the whole area. The crops grown are mainly citrus fruit, beetroot sugar, cereals, olives and alfalfa. The Tadla area is one of the largest irrigated areas in Morocco. It is characterized by a high rate of emigration and a combined use of groundwater and surface water, and a well-organised dairy industry (Cances, 2005; ABHOER, 2020).

The increasing shortage in surface water made farmers resort to groundwater through digging private wells and boreholes. During droughts of the early 1980s, the government subsidized the digging of wells and the installation of pumping stations and more than 7000 wells were digged (Hammani et al., 2006; Hammani & Kuper, 2007).

The aim of this research is to assess the changes in climate variables, specifically precipitation and temperature, as well as the alterations in cultivated land area and crop yields within the Tadla region. Furthermore, our investigation examines the trends associated of inflow into two dams (Bin El Ouidane and Ahmad El Hansali) and four aquifers (2 Turonian and 2 Eocene). That play a crucial role in supporting the irrigation processes necessary for crop cultivation in this area.

2. Study Area

The Tadla plain, located in the Oum Rbia river basin about 270 km east of Rabat, the administrative capital city of Morocco, is a vast syncline depression covering an area of about 3600 km^2. It has a topographic slope varying between 1 and 3%. It is crossed from east to west, approximately 160 km by the Oum Rbiaa river which divides it into two large parts with various hydraulic characteristics: Beni Amir in the north and Beni Moussa in the south (El Hammoumi et al., 2012).

On a physical level, The Tadla plain is the most homogeneous area of the region. It corresponds fully to the territory of Tadla which includes the largest irrigated area of the kingdom .It is an agricultural area thanks to the hydraulic potential that runs through it: the Oum Rbiaa river and its effluents (CRBK, 2019).

It includes the entire province of Fquih Ben Salah and part of the province of Beni Mellal. The population of Tadla is about 682,934 inhabitants according to the General Population and Housing Census of 2014. In 2004, this region encompasses a population of 39,958 inhabitants, an increase of 43% in one decade. It is the area with the highest density of human occupation i.e. 1.7 per hectare (117 inhabitants per km^2) (HCP, 2014).

The irrigated perimeter of Tadla extends over a practical agricultural surface of about 97,000 hectares. It comprises two distinct parts as shown on **Figure 1** separated by the Oum Rbia river: on the left bank the Beni Moussa zone covering an area of 69,500 hectare, on the right bank the Beni Amir zone with an area of 27,500 hectares (Kobry & Eliamani, 2004).

In the Beni Amir area, irrigation water comes from the Oum Rbia river from the Kasbaa-Tadla diversion dam. The volume of water used for irrigation in this area varies between 200 and 300 mm cubes depending on crop rotation and water availability. The Beni Moussa area is mainly irrigated by water from Bin El Ouidane dam with annual volumes of 500 mm cubes in both areas. The annual

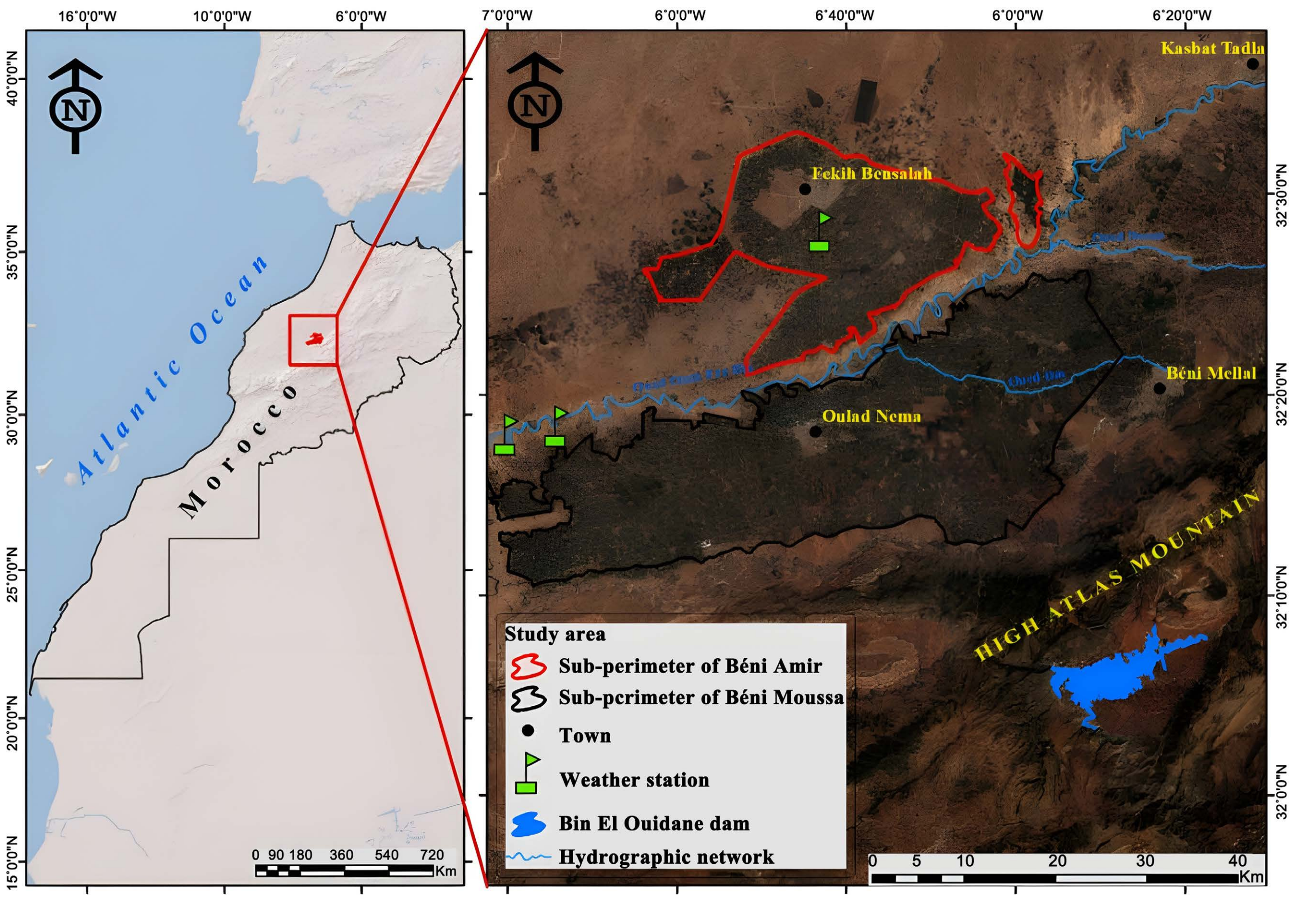

Figure 1. Geographic location of the study area (Chaaou et al., 2022).

withdrawals of water from the groundwater are estimated at 92 mm cubes and 40 mm cubes per year for Beni Amir and Beni Moussa respectively. The irrigation is essentially gravitational, the pivot irrigation system was introduced in a 3600 hectare sector in Beni Amir (El Hammoumi et al., 2012).

The deep aquifers of Tadla which include successively below the water table, the acquifer levels of the Eocene, the Senonian and the Senomano-turonian; the close relation which link these successive acquifer levels lead to consider them as a single hydraulic unit. The groundwater of the perimeter of Tadla and the two dams used on the irrigation of this perimeter are represented in the Figure 2.

3. Materials and Methods

3.1. Study Design

The parametric regression method was employed to comprehensively analyze the evolution of agricultural activities, focusing on two critical factors: cultivated area and crop yields. This allowed us to gain a deeper understanding of how these essential agricultural components have evolved over time.

For the assessment of hydrological trends, we employed non-parametric methods, namely the Theil-Sen slope and Mann-Kendall tests. These were instrumental in evaluating the trends related to water inflow into two dams crucial for irrigation in the study area, as well as the groundwater levels. By utilizing these methods, we were able to discern significant patterns and changes in these vital water resources that play a pivotal role in supporting agricultural practices.

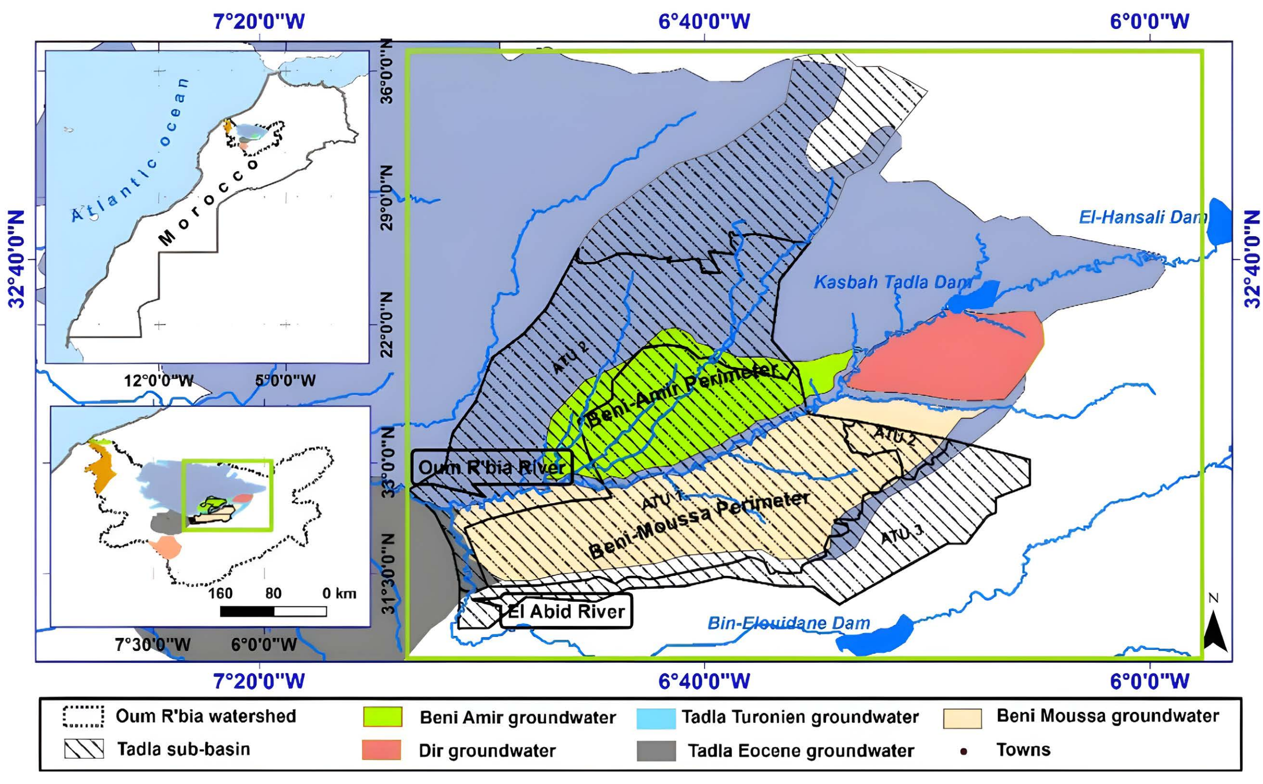

Figure 2. Groundwater of the zone study and localisation of the tow dams studied (Lionboui et al., 2018).

To quantify the precipitation deficit, we adopted the standardized precipitation index (SPI) method. Subsequently, we applied linear regression analysis to thoroughly examine the evolution of the SPI values. This step allowed us to identify and understand the trends in precipitation patterns over the studied period.

3.2. Data Analysis

For the analysis relating to agriculture in the region, we have chosen the last 10 years according to the availability of data. Crops studied in this paper are:

- Citrus fruit: navel and Washington oranges, lemons, clementine and grapefruits
- Cereals: wheat and soft cereal and barley
- Fodder: berseem and Alfalfa
- Sugar beet
- Olive tree

We used data of precipitations and temperature of the 10 last years from the Regional water agency using data of the station of Machraa Dahk, and the crop yeld and cultivated areas in Tadla perimeter in last 10 years from the Regional Office of Agricultural Development of Tadla and regional direction of agriculture. We used also piezometric data of 4 aquifers represented in **Table 1** below, and inflow dams of Bin el Ouidane and Ahmed Al Hansali over 10 year, between 2010 and 2020.

3.3. Methods Used

3.3.1. Trend Test

Broadly, statistical tests fall into two categories: parametric and non-parametric tests. Regression, Theil-Sen slope and Mann-Kendall tests are the most commonly employed parametric and non-parametric tests, respectively, for trend analysis in studies.

3.3.2. Mann-Kendall

Mann-Kendall (*MK*) test is a nonparametric test extensively used for the trend analysis of hydrological and climatic variables; it helps to understand the pattern of time-series data. Moreover, it does not require the data to be normally distributed and it has less influenced by raw and skewed data that's why received more popularity among other trend analysis methods (Spearman's rho test, Student's t test).

Table 1. Aquifers choosen.

Aquifers	Nature	N° IRE	X(m)	Y(m)	Z(m)
Turonien 1	borehole	776/37	430,547	224,045	586
Eocène 1	borehole	946/37	414,450	211,200	516
Turonien 2	borehole	1375/37	406,780	224,550	530
Eocène 2	borehole	2869/37	411,450	220,000	460

The *MK* test had been proposed by Mann (1945) as a nonparametric test for trend detection and Kendall (1975) formulated the test statistic. It is essentially limited to test the null hypothesis that no trend exists in the data, without estimating the amplitude of change. It is a free distribution test; no assumption regarding the normality of the data is required. However, there must be no serial correlation for the resulting p values to be correct and the distribution must remain constant.

The null hypothesis for this test is that there is no trend, and the alternative hypothesis is that there is a trend in the two-sided test or that there is an upward trend (or downward trend) in the one-sided test. For the time series $x_1, \ldots, x_m$, the *MK* Test uses the following statistic in the Equation (1) and (2):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right) \tag{1}$$

$$\operatorname{sgn}(x) = \begin{cases} 1, & X > 0 \\ 0, & X = 0 \\ -1, & X < 0 \end{cases} \tag{2}$$

Note that if $S > 0$ then later observations in the time series tend to be larger than those that appear earlier in the time series, while the reverse is true if $S < 0$.

The variance of S is given by the Equation (3):

$$\operatorname{var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i i(i-1)(2i+5)}{18} \tag{3}$$

where n: sample size

t_i is the number of links of scope i

The *MK* Test uses the following test statistic in the Equation (4):

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\operatorname{var}(S)}, & S > 0 \\ 0, & S = 0 \\ \dfrac{S+1}{\operatorname{var}(S)}, & S < 0 \end{cases} \tag{4}$$

The standardized statistic Z_{MK} follows the standard normal distribution with a mean of 0 and a variance of 1.

3.3.3. Theil-Sen Slope

The Theil-Sen estimator, also known as Sen's slope estimator, slope selection, the single median method, or the Kendall robust line-fit method, is a method for robust linear regression that chooses the median slope among all lines through pairs of two-dimensional sample points. Proposed by Theil (1950) and Sen (1968) and later extended by Hirsch et al. (1982).

The estimator is nonparametric, which means that it doesn't draw from any particular probability distribution. It is an alternative to the parametric least-squares regression line where least squares uses a weighted mean to estimate the slope, Sen's uses a median.

3.3.4. Regression Test

Parametric methods, in general, rely on establishing a regression connection between the time series of a variable and the time parameter. Furthermore, in accordance with the assumptions underpinning these methods, it is necessary to presume a probability distribution for the time series. In order to yield dependable outcomes through parametric techniques, it becomes crucial to assess the soundness of this presumption. Moreover, maintaining a constant variance in the data and ensuring the independence of observations constitute the primary prerequisites for parametric regression methods (Gajbhiye et al., 2016).

3.3.5. Estimation of the Standardized Precipitation Index

The SPI index (McKee et al. 1993, 1995) is an index that is powerful, flexible to use and simple to calculate. Rainfall data is actually the only required parameter. In addition, the SPI index is just as effective in analyzing wet periods or cycles as dry periods or cycles (WMO, 2012).

The SPI index was designed to quantify the precipitation deficit at multiple time scales. These time scales reflect the impacts of drought on the availability of different types of water resources. Soil moisture responds relatively quickly to precipitation anomalies, while groundwater, stream flow, and reservoir storage volumes are sensitive to longer-term precipitation anomalies. This is why McKee et al. (1993) initially calculated the SPI index for time periods of 3, 6, 2, 24 and 48 months.

The 9-month SPI index provides an indication of inter-seasonal precipitation patterns, at medium range. It usually takes at least one season for drought conditions to set in. An SPI index established over 9 months and presenting values lower than −1.5 is usually a good indicator of dry conditions with significant consequences for agriculture and which can affect other sectors as well. For some regions, we will find that the cartographic representation of the Palmer index corresponds quite well to that of the SPI index over 9 months. For other regions, the approximation will be more between the Palmer index and the SPI index over 12 months. It is from 9 months that we begin to establish the link between a short-term seasonal drought and a longer-term drought that can turn into a hydrological drought or a drought extending over several years (WMO, 2012).

It is based on the cumulative probability of precipitations at an observation point and given by the Equation (5):

$$G(x) = \frac{1}{\beta\tau(\alpha)}\int_0^x \frac{e^{\frac{x}{\beta}}}{x^{\alpha}}\mathrm{d}x \tag{5}$$

where α is a shape parameter, β is a scaling parameter, x is the precipitation quantity, and $\tau(\alpha) = \int_0^{\infty} y^{\alpha-1}\mathrm{e}^{-y}\mathrm{d}y$ is the gamma function.

The cumulative distribution function is changed into the standard normal distribution by using, for example, the approximate conversion provided by Abramowitz & Stegun (1972), using the Equations (6)-(9).

$$Z = \text{SPI} = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \tag{6}$$

$$t = \sqrt{\ln\left(\frac{1}{\left(H(x)\right)^2}\right)} \text{ for } 0 < H(x) < 0.5 \tag{7}$$

$$Z = \text{SPI} = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \tag{8}$$

$$t = \sqrt{\ln\left(\frac{1}{\left(H(x)\right)^2}\right)} \text{ for } 0.5 < H(x) < 1 \tag{9}$$

4. Results and Discussion

4.1. Evolution of Agricultural Activities

4.1.1. Analysis of the Cultivated Area

Citrus fruit

In 2008, the total cultivated area for citrus was about 5.4 million hectares, of which oranges covered 4.2 million hectares, lemons and limes together 1.02 million hectares and grapefruits 0.25 million hectares representing 80% of the total world production (86 million *t*) of citrus. Lemon and lime with 15% and grapefruit 5% (Carr, 2012).

The results showed that the cultivated area of the different citrus species selected in the irrigated area of Tadla has increased in recent years for the different citrus species and varieties cultivated in the study area, with the exception of the Clementine area whose area has decreased since 2014 (**Figure 3**).

In fact, the cultivation of navel orange has increased from 2558 in 2010 to 2690.89 hectares in 2016 and the year of 2021 recorded a cultivated area of 3843.01 hectare, an increase of 11.14%.

The area under lemon cultivation, on the other hand, has tended to increase over the last ten years, from 177 ha in 2010 to 230 ha in 2021, which is equivalent to an increase of 48%. Clementine has increased by 11.34% during the 2010-2021 period. Grapefruit has recorded a very high percentage increase over the last few years, i.e. 200%, and Washington orange 21.6%.

Research from the University of Arizona has shown that the water requirements of citrus trees depend on tree age and size, citrus species, climate and tree type. Water consumption for grapefruits and lemons is about 20% higher than that of oranges while water consumption for mandarins is about 20% lower. Trees planted in grass should receive about 20% more water than trees without grass or ground cover. In addition, mature citrus trees use about 1524 mm of water per day in summer (Wright, 2000).

Cereals

The cereals occupy an important surface in the perimeter of Tadla. Concerning the income generated by the agriculture of the region, cereals come in the

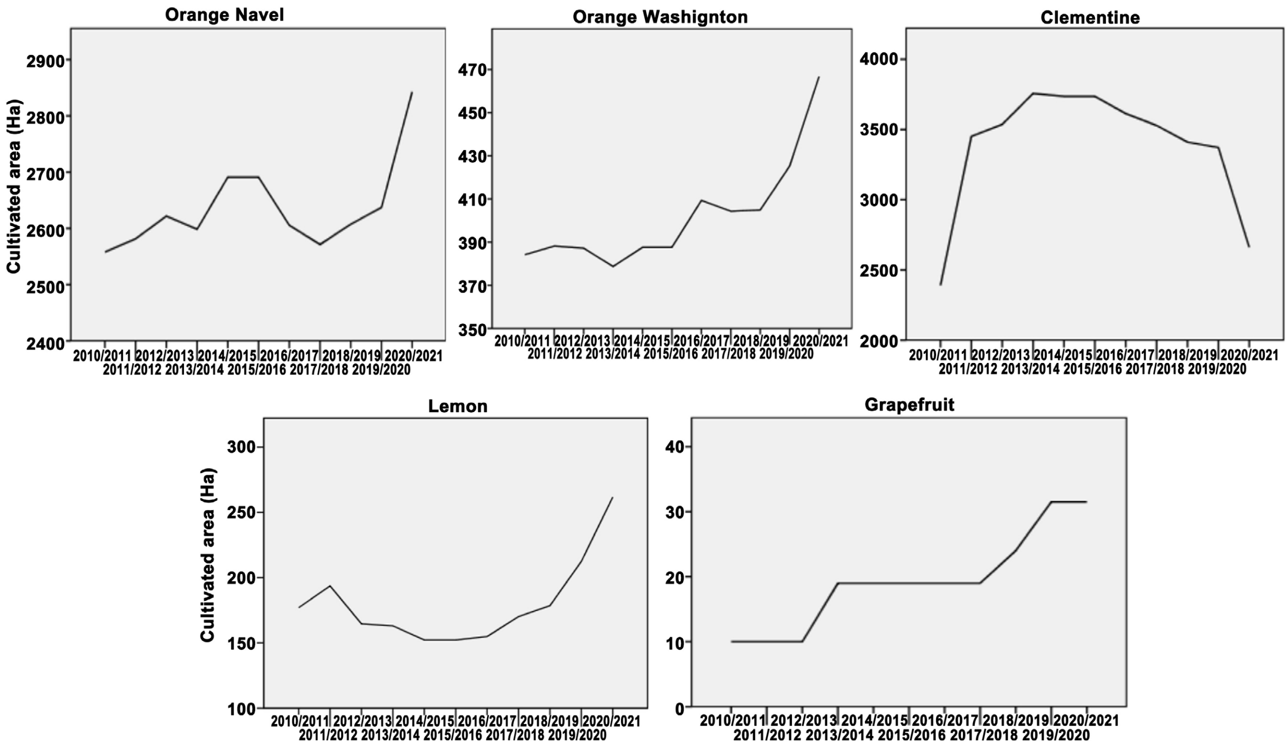

Figure 3. Evolution of cultivated area of different species of citrus fruits (Ha) during the period 2010-2020.

first place, followed by other crops such as olive trees, citrus fruits and beetroot. In this work, we have concentrated on three types of cereals: These are wheat and soft cereal and barley. The evolution of the cultivated areas during the last 10 years is represented in the **Figure 4**.

According to the data of the last ten years, we notice that the cultivated areas of wheat and barley cereal have a tendency to increase (**Figure 4**). In fact, for wheat the cultivated areas during the period 2014-2021 are higher compared to the previous years. The cultivated areas of wheat have increased from 11,000 hectare in 2010 to 13,360 hectare in 2020, that is to say, an increase of 21.5%. On the other hand, the year 2022 has known a decrease of cultivated area of 19.5 hectare in comparison to 2021, while barley has increased from 200 hectare in 2010 to 514 hectare in 2021. The area under wheat cultivation has tended to decrease during the study period, from 44,200 hectare in 2010 to 620,790 hectare in 2021.

The irrigation requirements of cereals are lower than those of other species, at an amount of 300 mm and 150 mm respectively (El Hafyani et al., 2021).

The results of Boughdiri et al. (2014), showed that the water requirements of irrigation for wheat were 144 mm; the amount of water supplied was 100 mm respectively in the plot of the state farm and private farm. The water requirements of wheat crop vary from 450 to 650 mm (FCAM, 2018).

On the other hand, irrigation water requirements for barley depend on variety, on climatic conditions (temperature and rainfall) and the target yield. To achieve optimum yield, barley needs between 390 and 430 liters of water.

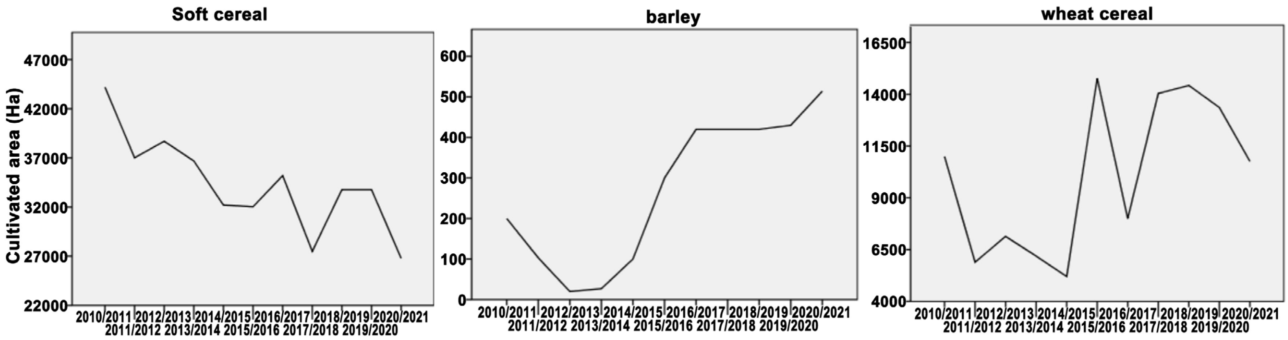

Figure 4. Evolution of cultivated area of cereals (Ha) during the period 2010-2020.

Fodder

We notice that both cultivated areas of the two types of fodder have a tendency to increase as shown in Figure 5. In fact, the cultivation of alfalfa has increased from 28,348 ha in 2010 to 31,062 ha in 2021, however, both years 2016/2017 have recorded decreases in cultivated areas. The area under berseem clover has increased during the previous years.

According to the study, the volumes of water supplied to alfalfa and berseem have averaged 16,750, 4965, 75,700 mc/ha respectively. The farmers who do not have groundwater do not manage to irrigate sufficiently and provide an average of 8750 mc/ha, whereas those who use both resources apply an average of 18,350 mc/ha. This volume can reach about 25,000 mc/ha for some farmers (Hammani et al., 2008).

Sugar beet and Olive tree

The area under sugar plants cultivation has increased in 2010 and 2018, but as for the year 2019, the area under sugar beet cultivation has decreased by 46.6% as shown in Figure 6. Sugar beet is a plant that requires a significant amount of water (600 - 700 mm) for the production of 90 tons (800 - 900 mm).

Over the past decade, there has been a significant growth in olive cultivation areas. From 2010 to 2021, these areas expanded from 12302.13 hectares to 29689.81 hectares, marking an impressive increase of over 100% as shown in Figure 7. This expansion underscores the increasing importance of olive cultivation in our society.

Especially in semi-arid regions, olive cultivation comes with specific water supply requirements. Olive trees in these regions require approximately 65% of potential evapotranspiration (ETP), which amounts to a water quantity ranging from 4000 to 5000 cubic meters per hectare. This quantity of water is distributed over 15 to 20 irrigation cycles, following the recommendations of INRA (INRA, 2002).

The increase in cultivated areas is the result of the strategies and actions recommended by the Green Morocco Plan, which was launched in April 2008 and represents a very ambitious strategy aimed at making the Moroccan agricultural sector a real lever of socio-economic development in the kingdom through the acceleration of growth, the reduction of poverty and the consolidation of the integration of agriculture into national and international markets.

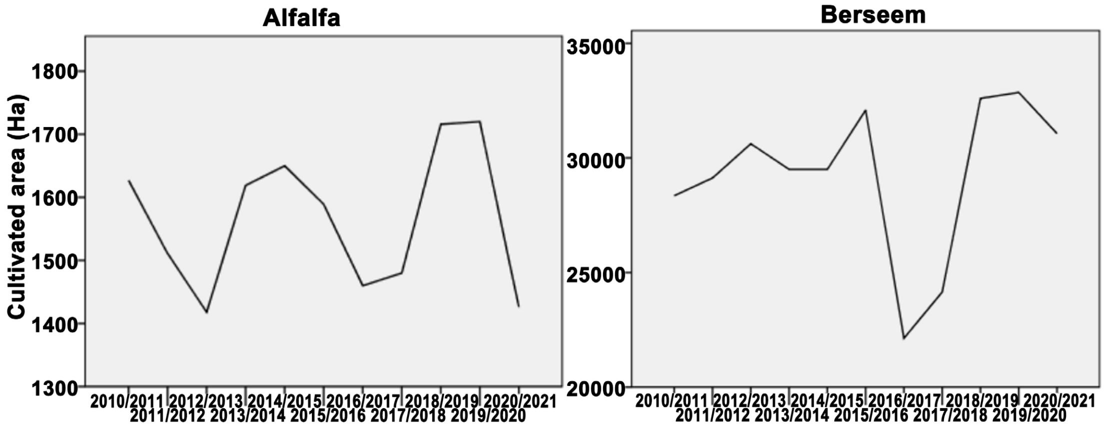

Figure 5. Evolution of cultivated area of fodder (Ha) during the period 2010-2020.

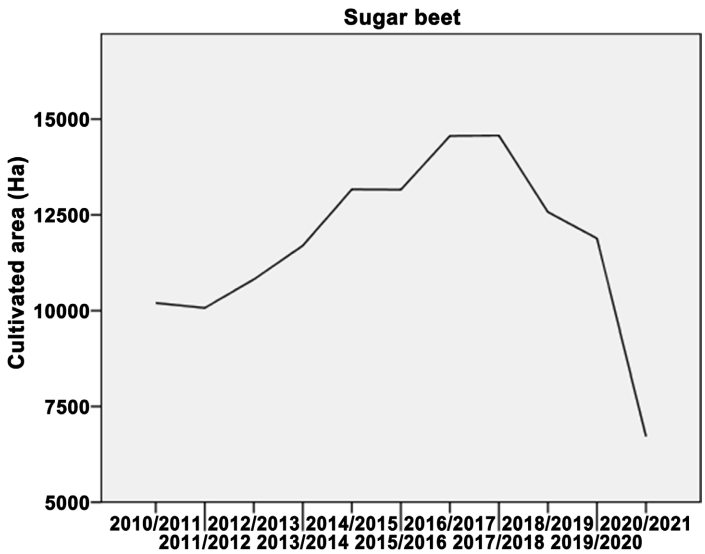

Figure 6. Evolution of cultivated area of sugar beet (Ha) during the period 2010-2020.

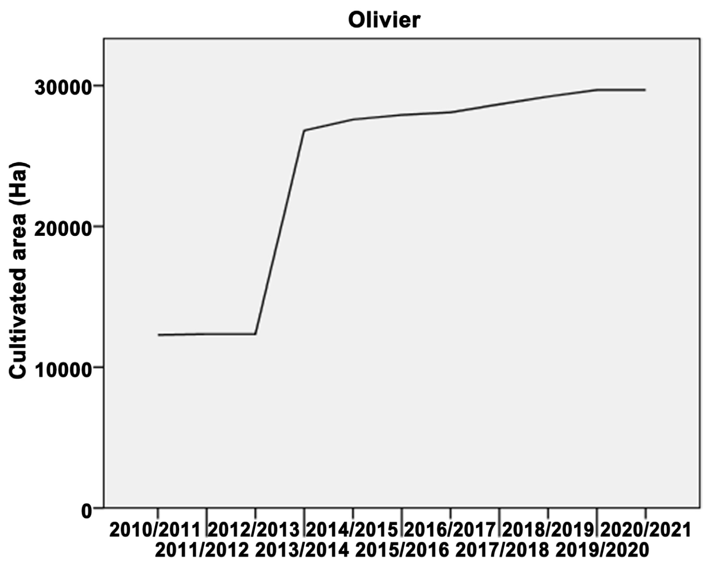

Figure 7. Evolution of cultivated area of olive tree (Ha) during the period 2010-2020.

Morocco has, in a few years, considerably increased the public investments allocated to the agricultural sector, which has notably resulted in an increase of the cultivated surfaces, arousing the interest of many actors of agricultural development (IRDR, 2016).

The increase of these cultivated surfaces requires very important quantities of water for irrigation, and in a context marked by an increase in shortage of surface water due to recent droughts and an intense competition between the sectors users of water (agriculture, AEPI and tourism) the massive resort to groundwater became a necessary practice for the intensification and the agricultural diversification.

The expansion of cultivated areas is a double-edged sword in the realm of agriculture. While it can potentially lead to increased production and economic growth, it often comes at the cost of overexploiting our precious water resources. This overexploitation poses significant challenges, as it can deplete aquifers and surface water supplies, leading to long-term consequences for both agriculture and the environment.

The key to successful and sustainable agricultural practices lies in understanding the delicate balance, between the expansion of cultivated land and the availability of water resources. Precipitation rates, for instance, are a critical factor in this equation. They directly influence soil moisture levels, affecting crop growth, development, and yield. Adequate and timely rainfall can provide the necessary moisture for crops, reducing the need for excessive irrigation.

Furthermore, the availability of water resources for irrigation is paramount for ensuring high yields and improving the quality of agricultural products. Properly managed irrigation systems can mitigate the impact of erratic rainfall patterns and droughts, enabling consistent crop production. Efficient irrigation techniques also contribute to minimizing water wastage, which is especially crucial in regions facing water scarcity. The analysis below has shown us what we are currently expressing.

4.1.2. Analysis of the Crop Yield

Citrus fruits

The dynamics of Washington orange have undergone significant shifts between 2017 and 2020 (**Figure 8**). During this period, the cultivated area dedicated to Washington oranges has notably expanded. However, this expansion hasn't translated into an increase in production; instead, there has been a concerning decreases in the yield of Washington oranges.

In contrast, the trends for lemon and clementine cultivation have followed a similar trajectory. The acreage allocated to growing lemon and clementine trees has seen a considerable rise during the same three-year span. Yet, like the situation with Washington oranges, this increase in cultivation area has not resulted in higher production. In fact, the production of both lemon and clementine has declined during this period.

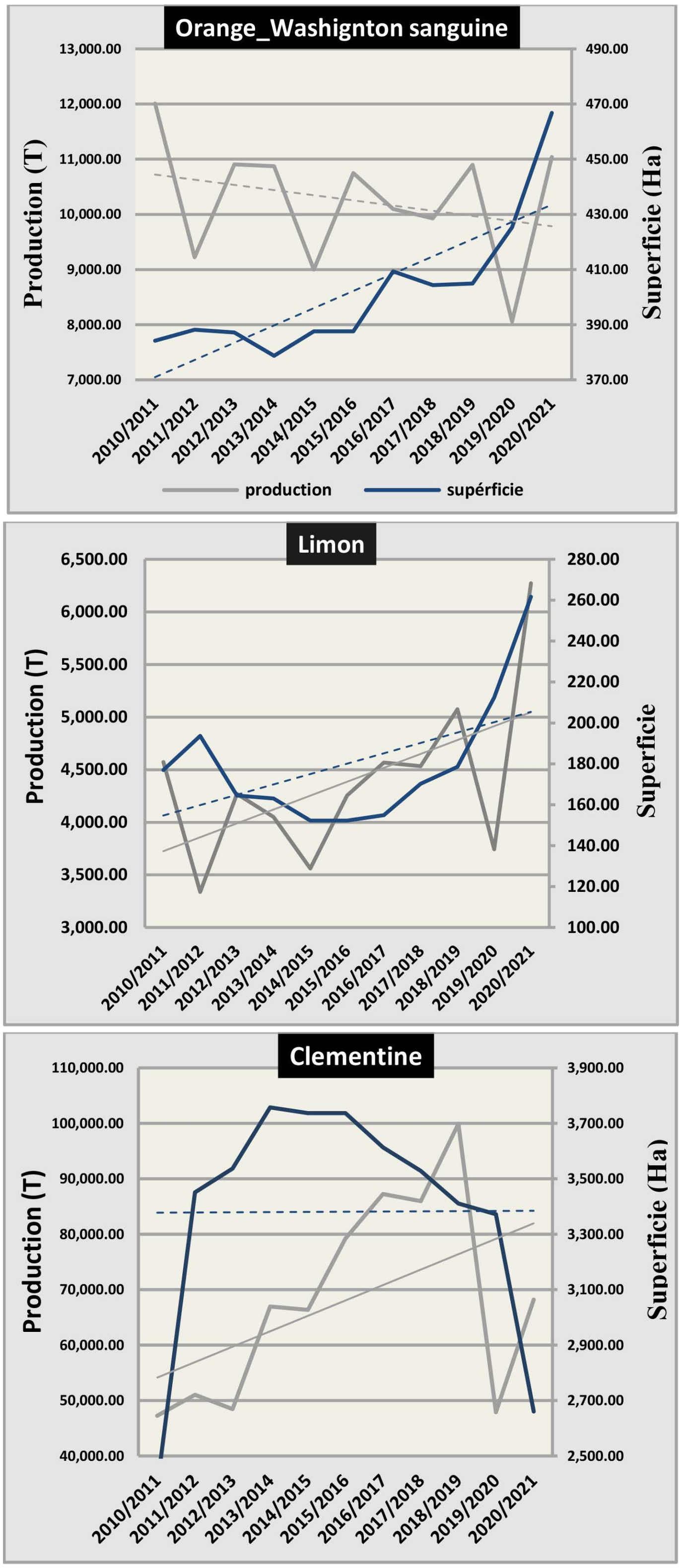

Figure 8. Evolution of the production of citrus fruits.

Cereals

Since wheat is more sensitive to cold than soft wheat, and more resistant to drought, the area and production of soft wheat decreased, while that of wheat increased throughout the study period. As for barley, production increased with an improvement in the area cultivated during the study period, except for the three years 2016/2018 (Figure 9). In fact, barley is classified as one of the cereals

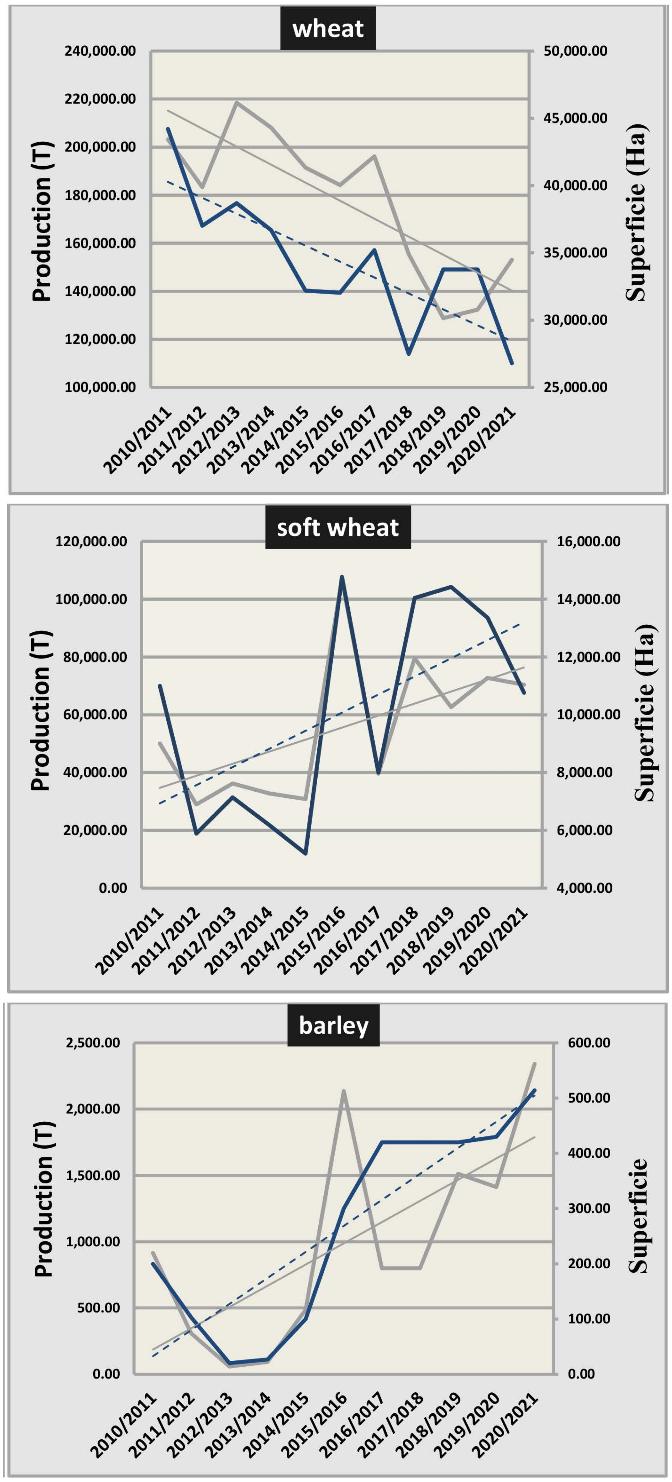

Figure 9. Evolution of the production of cereals.

that do not consume much water, 856 cubic meters/ha, while wheat requires 2852 cubic meters/ha (Ozkan et al., 2004). It has the capacity to adapt to several abiotic stresses (drought, salinity, etc.) (This & Teulat-Merah, 2000).

Drought is considered the most important factor limiting cereal production. It is one of the first factors limiting yields and is the first abiotic constraint that leads to differences not only between average and potential yields, but also between the different cereal companions (Slama et al., 2005).

Fodder

The data presented in the graphs (**Figure 10**) yields valuable insights into the production trends of two important crops: berseem clover and alfalfa. Firstly, when focusing on berseem clover, the figures show a significant shift in production dynamics. Until the year 2017, there was a consistent upward trajectory in berseem clover production, with quantities steadily increasing. However, from 2017 onward, there was a notable decline, with production dropping from 94760.00

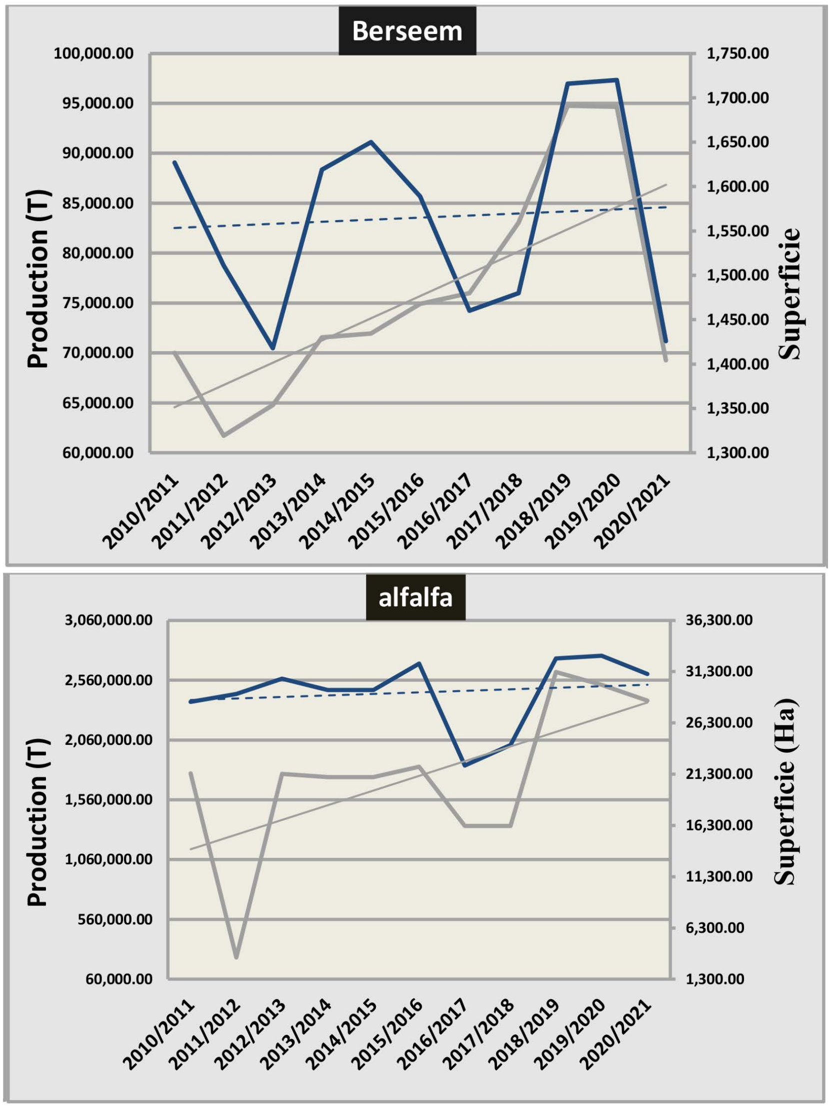

Figure 10. Evolution of the production of fodder.

tons to 69265.00 tons. This sharp decrease indicates a shift in the factors influencing berseem clover cultivation, suggesting that conditions for its growth or demand for this crop may have changed significantly during this period.

On the other hand, when considering alfalfa, the trend is distinct. Unlike berseem clover, alfalfa production started to experience a gradual decline beginning in 2018. This decrease in alfalfa production has been ongoing, and the data highlights that it is a concerning trend.

Sugar plants

We can see that between 2015 and 2018 the production has decreased even if the cultivated areas have increased, since 2019, the surface area and the production have decreased (**Figure 11**).

The main limitation to the world production of sugar beet is water stress, so that a better tolerance to drought in cultivars can lead to improvements in yield, area cultivated and crop productivity (Ghaffari et al., 2019). In fact the sucrose content of sugar beet decreases under water stress due to the accumulation of ions and solutes (Ghaffari et al., 2021).

Olive trees

The trends in olive trees cultivation and production between 2015 and 2018 (**Figure 12**) raise significant questions about the dynamics of this agricultural sector. During this initial period, it is notable that despite an expansion in the cultivated areas dedicated to sugar beet farming, there was a concerning decrease in production.

The situation becomes more troubling from 2019 onward, as both the surface area under sugar beet cultivation and production figures have experienced declines. This synchronized decrease suggests the presence of more systemic issues affecting the sugar beet industry. Economic factors, such as fluctuating commodity prices or increased production costs, may have discouraged farmers from planting sugar beets, leading to a reduction in cultivated areas. Simultaneously, these factors may have impacted production levels due to decreased investment in crop management practices.

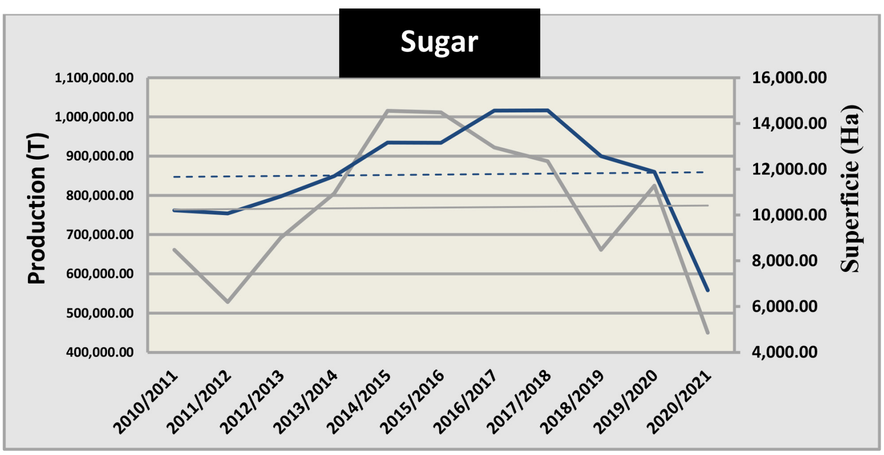

Figure 11. Evolution of the production of sugar beet.

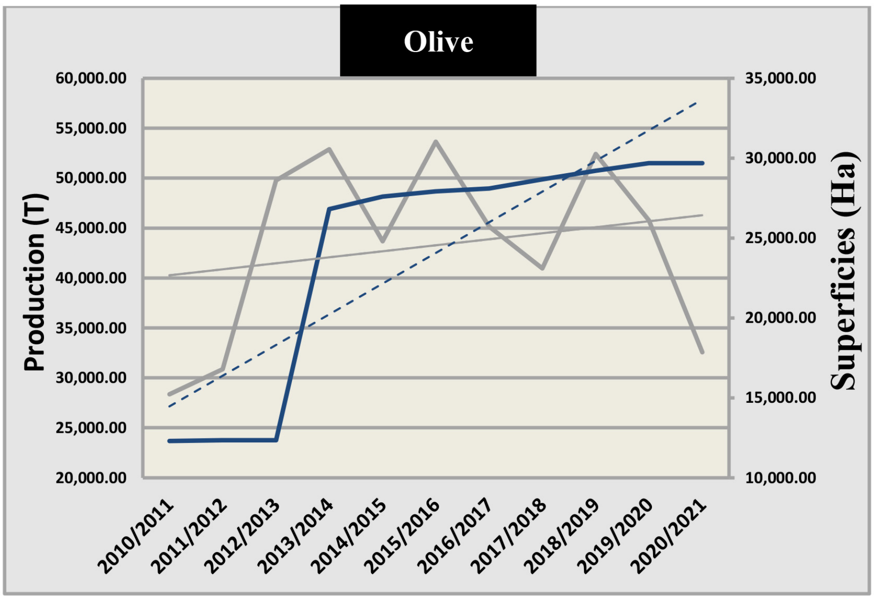

Figure 12. Evolution of the production of olive tree.

We notice that since the year 2017, the production has decreased even if the cultivated areas have increased during the whole study period.

The area planted with olive trees at the national level increased to nearly 680,000 ha, i.e. more than 37% of the national orchard. Although the olive tree covers the whole national territory, the geographical distribution of this heritage shows four large olive-growing areas of which the irrigated area represents 240,000 hectares, i.e. almost 37% of the total area planted with olive trees. With well distributed 600 mm, the olive tree normally grows and produces between 450 and 600 mm, the production is possible on condition that the water retention capacity of the soil is sufficient (deep clay-loam soil). With a rainfall of less than 200 mm, olive growing is economically unprofitable (PACAM, 2020).

4.1.3. Evolution of Irrigation Water

Groundwater level trend

The importance of groundwater resources in the irrigated area of Tadla was revealed during the years of drought 1981-1984 causing a shortage of surface water. Since then, the use of groundwater has become systematic, taking into consideration the recurrent shortage of surface water in the OumRbiaa basin (Hammani et al., 2006).

Kwelde (2006) has demonstrated that in his research that the Access to groundwater has a significant impact on crop yields, with notable increases of up to 87% for durum wheat, 81% for olive trees, and nearly 10% for alfalfa.

At a 95% confidence level, we utilized the *MK* test and Sean's slope estimator to evaluate both the significance and magnitude of trends in the piezometric data for the four aquifers. The outcomes of the trend analysis are presented in **Table 2**, offering valuable insights into the behavior and changes in the groundwater levels over the studied period. This statistical analysis allows us to confidently

Table 2. Trend analysis results.

Aquifers	Parameters			
	Sen's slope	Kend tau	*S*	*p*-value
Turonien 1	4.683	0.909	119617	0.0001
Eocene 1	3.327	0.422	224875	0.0001
Turonien 2	8.5085	0.667	2733	0.0001
Eocene 2	3.619	0.746	109417	0.0001

assess the direction and strength of trends within the aquifers levels data, providing important information for understanding hydrological dynamics and potential environmental implications.

The groundwater level data observed throughout the entire study period has consistently indicated a notable upward trend across various aquifers. This trend is substantiated by statistical analysis, where all computed p-values are found to be significantly lower than the chosen significance level, denoted as q-value, which is set at 0.05. This statistical result underscores the robustness of the observed trend, implying that the rise in piezometric levels within these aquifers is statistically significant and not merely a chance occurrence.

The water tables of Tadla are currently experiencing a significant decline. The scarcity of surface water, agricultural intensification and advances in drilling technology are the main factors that accentuate this overexploitation. In the recent years the network of private wells and boreholes has developed strongly, leading to a significant decline in the level of groundwater.

The observed decline in piezometric levels can be attributed to a combination of factors, with climate changes and the overexploitation of water resources emerging as primary culprits. According to the research of Meddi & Eslamin (2021), deficit of precipation had a negative influence on the water resource and crop yield

Climate changes have brought about shifts in precipitation patterns and increased temperatures, impacting the natural replenishment of aquifers. Extended periods of drought, reduced snowmelt, and altered rainfall distribution have led to decreased groundwater recharge. This diminished recharge capacity exacerbates the strain on available water sources, contributing to the decline in piezometric levels.

Moreover, the agricultural sector, which accounts for roughly 80% of water resource consumption in the region, plays a significant role in depleting groundwater reservoirs. The sector's intensive irrigation practices, especially in response to water-demanding crops, exert immense pressure on aquifers and surface water supplies. The excessive extraction of water for agricultural purposes not only depletes available resources but also interferes with the natural equilibrium of groundwater systems, further lowering groundwater levels.

Inflow dams trend

The surface water used for irrigation in the study area comes from the dams dam Bin El Ouidane on the Oued El Abid and Ahmed El Hansali on the Oum Er Rbia. Regression analysis is conducted with time as the independent variable and inflow dams as the dependent variable, in order to analyze the evolution trend of water inflow of the two dams.

Results of analyzing trends in all months (Figure 13) show significantly decreasing trends for water inflow over the statistical period in both dams. only one month showed positive trend (August in Ahmed El Hansali dam).

For Ahmad El Hansali: The coefficients clearly illustrate a consistent trend of decreasing water inflows from September through February. This decline in water inflows is particularly pronounced during the winter months, with February (−27.975) and January (−15.932) experiencing the most substantial reductions. These findings strongly imply that water availability tends to diminish significantly during the winter period in Ahmad El Hansali. This trend can have significant implications for water resource management and highlights the need for careful planning and conservation efforts to ensure an adequate water supply during this season.

For Bin El Ouidane: Similarly, the coefficients for Bin El Ouidane reveal a notable pattern of decreasing water inflows, but during a different time frame. From March to July, there is a consistent decline in water inflows, with March (−23.716) displaying the most substantial decrease. This trend suggests that the spring and early summer months experience a significant reduction in water availability in the Bin El Ouidane region. However, there is a glimmer of hope as August shows a slight upward trend (0.194), indicating a possible recovery in water inflows towards the end of summer. This slight increase in August could provide some relief in terms of water resources, potentially mitigating the earlier decreases in the season.

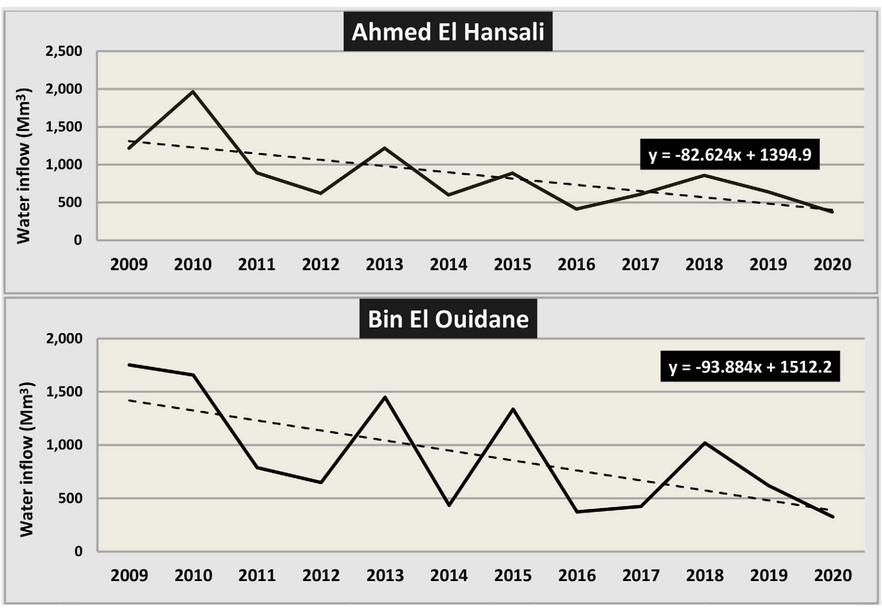

Figure 13. Evolution of the annual water inflow.

4.2. Evolution of Climate Parameters

Climate generally affects agricultural water use in two different ways. The first is that by altering key components of crop growth such as precipitation, evaporation, and solar radiation, a changing climate will have a direct impact on the supply and demand for agricultural water. Secondly, there is a significant impact of climate on crop yields, which indirectly affects their water productivity. During recent decades, there has been no significant change in the global amount of precipitation, but global warming has caused a significant change in evaporation (Cai et al., 2015).

The region of Beni-Mellal Khenifra is characterized by a semi-arid climate and by a very high agricultural vulnerability due to the climate variability. In our previous studies, we have demonstrated that the temperature are unstable and trend to increase in different areas of the region including Tadla plaine (EL Baki et al., 2021).

The results of the SPI (Standardized Precipitation Index) obtained using data from the Machraa Dahk station show that the study area underwent a significant rainfall deficit between 2016-2020, their intensity varies from moderate to severe.

Regarding the period from 2016 to 2020, it is worth noting that nearly all of the average SPI values during this time frame were in the negative range, indicating a significant and persistent drought throughout this period. The minimum SPI recorded during these years was as low as −1.85, emphasizing the severity of the drought conditions experienced.

The percentages of SPI values are 16.7% for the three wet cycles and 71% for the close to the normal cycle and 12.3% for the dry cycles (**Figure 14**). Over the course of the past decade, the results consistently portray a recurring trend of precipitation deficits, with the situation intensifying notably since 2016. This long-term deficit in precipitation underscores the pressing need for effective water resource management and mitigation strategies to address the challenges posed by these extended periods of drought.

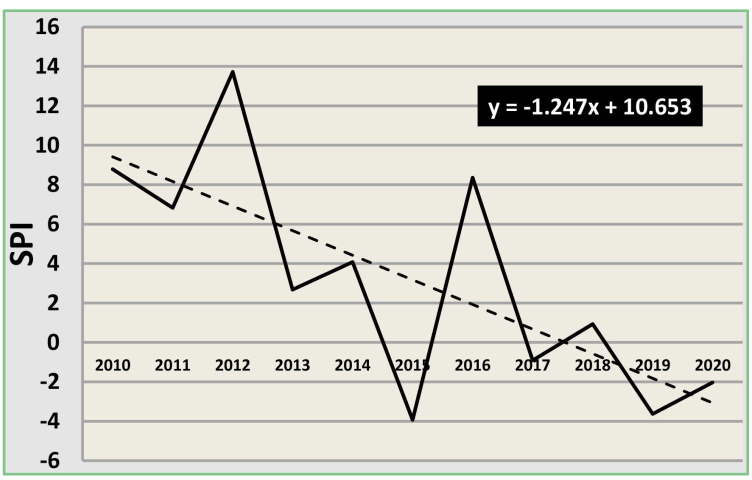

Figure 14. Evolution of SPI values.

These findings align with the results presented in the studies by Ait ouhamchich et al. (2018), Tahiri et al. (2022) and Boundi & Ait Yacine (2021) all have documented a noticeable increase in both temperature and precipitation patterns.

5. Conclusion

In conclusion, our study sheds light on several critical aspects of agricultural dynamics in the Tadla region. A significant expansion of cultivated areas has been observed for several key crops, such as citrus, cereals, fodder, sugar plants, and olive trees. This expansion can be attributed to the strategic initiatives outlined in the Green Morocco Plan, which prioritizes the enlargement of cultivated areas, crop diversification, and enhanced production. However, it's important to note that this increase in cultivated land hasn't universally translated into improved crop yields. Some crops have experienced a decline in yields, raising questions about the role of precipitation deficits observed in recent years. We used the Standardized Precipitation Index (SPI) method to assess the impact of these deficits and found that, starting from 2016, SPI values have been consistently low, often negative or close to zero. This initiates the discussion about the strong influence of weather and climate conditions on agricultural production. In the absence of sufficient rainfall and suitable temperatures, crops face difficulties, and pastures become unproductive. This prompts further investigation into the intricate relationship between climate variability and agricultural yields, which will be a focal point of our future research.

Moreover, due to the persistent shortfall in rainfall, the extensive reliance on water resources (Whether it be water surface or groundwater), has become a fundamental practice for intensifying and diversifying agriculture. To examine the evolution of piezometric levels in the study area, we analyzed groundwater level data from four aquifers using the Mann-Kendall test. Our findings revealed a consistent upward trend in piezometric levels across all four aquifers, reflecting the increasing importance of groundwater resources in sustaining agricultural activities. These results underscore the vital role that climate, water resources, and agricultural practices play in the complex interplay that defines the agricultural landscape in the Tadla region.

The expansion and intensification of agricultural activities within the study area have exerted immense pressure on the available water resources. Both surface water and underground aquifers have been subject to significant overutilization. This overexploitation is primarily a consequence of the increasing demand for water to irrigate crops, sustain livestock, and support the growing agricultural sector. In addition to this overexploitation, the region has grappled with the challenges posed by changing climatic conditions. Precipitation deficits, characterized by reduced rainfall and altered precipitation patterns, have become increasingly prevalent. These deficits lead to insufficient natural replenishment of water sources, making them even more susceptible to overuse. Moreover, rising temperatures in the region exacerbate the situation. Higher temperatures increase evaporation rates, causing more rapid water loss from surface reservoirs and further stressing the available water supply. These temperature-induced changes also affect crop growth cycles, requiring more frequent and extensive irrigation to maintain agricultural productivity.

Taken together, the combination of agricultural expansion, overexploitation of water resources, precipitation deficits, and temperature increases presents a complex and challenging scenario. Sustainable water resources management practices, careful resource allocation, and climate-resilient agricultural strategies, and the adoption of strategies and proven technologies that enhance the combined utilization of rainwater and limited water resources in supplementary irrigation systems have become essential for improved and sustainable water productivity to mitigate the adverse impacts on water availability and ensure the long-term viability of agriculture in the region.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

ABHOER (Oum Errabia Hydraulic Basin Agency) (2020). *Study for the Update of the Integrated Water Resources Management Master Plan for the Oum Errabia Hydraulic Basin, Morocco*.

Abramowitz, M., & Stegun, I. A. (1972). *Handbook of Mathematical Functions* (p. 361). Dover Publications.

Ait Ouhamchich, K., Karaoui, I., Arioua, A., Kasmi, A., Elhamdouni, D., Elfiraoui, F. E., Arioua, Z., Nazi, F., & Nabih, N. (2018). Climate Change Trend Observations in Morocco: Case Study of Beni Mellal-Khenifra & Darâa-Tafilalt Regions. *Journal of Geoscience and Environment Protection, 6,* 34-50.

Arora, N. K. (2019). Impact of Climate Change on Agriculture Production and Its Sustainable Solutions. *Environmental Sustainability, 2,* 95-96. https://doi.org/10.1007/s42398-019-00078-w

Babqiqi, A. (2014). *Changements Climatiques au Maroc: Etude du cas de la Région de Marrakech Tensift Al Haouz et implications sur l'agriculture à l'horizon 2030*. Ph.D. Thesis, Cadi Ayyad University, Morocco.

Boughdiri, A., Ben Nouna, B., Hammami, M., Daghari, H., & Saidi, A. (2014). Modeling Water Requirements for Wheat and the Effect of Supplementary Irrigation in the Semi-Arid Regions of Tunisia. *Annales de l'INRGREF, 19,* 204-215.

Boundi, A., & A. Ait Yacine (2021). Study of Variability Rainfall Regime in an Agricultural Region with a Semi-Arid Climate: Case of Tadla Irrigated Perimeter (Continental Morocco). *Caspian Journal of Environmental Sciences, 19,* 31-45.

Cai, X., Zhang, X., Noël, P. H., & Shafiee-Jood, M. (2015). Impacts of Climate Change on Agricultural Water Management: A Review. *WIREs Water, 2,* 439-455. https://doi.org/10.1002/wat2.1089

Cances, A. L. (2005). *Diagnosis of Production Systems in the Tadla Irrigated Area (Morocco): What Are the Factors of Transformation and Differentiation of Agricultural*

Farms and Their Influence on Their Evolution? Ph.D. Thesis, National Higher School of Agronomy and Food Industries.

Carr, M. K. V. (2012). The Water Relations & Irrigation Requirements of Citrus (*Citrus* spp.): A Review. *Experimental Agriculture, 48,* 347-377. https://doi.org/10.1017/S0014479712000038

Chaaou, A., Chikhaoui, M., Naimi, M. M., El Miad, A. K., Achemrk, A., Seif-Ennasr, M., El Harche, S. (2022). Mapping Soil Salinity Risk Using the Approach of Soil Salinity Index and Land Cover: A Case Study from Tadla Plain, Morocco. *Arabian Journal of Geosciences, 15,* Article No. 722. https://doi.org/10.1007/s12517-022-10009-5

CRBK (Regional Council of Mellal-Khenifra) (2019). *Study on the Development of the Regional and Land Use Plan for the Beni Mellal-Khenifra Region*. http://www.benimellalkhenifra.ma

Eddoughri, F., Lakammarte, F. E., Eljarroudi, M., Lahlali, R., Karmaoui, A., Khebiza, M. Y., & Messouli, M. (2022). Analysis of the Vulnerability of Agriculture to Climate & Anthropogenic Impacts in the Beni Mellal-Khénifra Region, Morocco. *Sustainability, 14,* Article 13166. https://doi.org/10.3390/su142013166

EL Baki, Y., Boutoial, K., & Medaghri-Alaoui, A. (2021). The Impact of Climate Change on Water Inflow of the Three Largest Dams in the Beni Mellal-Khenifra Region. *E3S Web of Conferences, 314, Art*icle No. 03002. https://doi.org/10.1051/e3sconf/202131403002

El Hafyani, M., Essahlaoui, A., Fung-Loy, K., Hubbart, J. A., & Van Rompaey, A. (2021). Assessment of Agricultural Water Requirements for Semi-Arid Areas: A Case Study of the Boufakrane River Watershed (Morocco). *Applied Science, 11*, Article 10379. https://doi.org/10.3390/app112110379

El Hammoumi, N., Sinan, M., Lekhli, B., & El Mahjoub, L. (2012). Assessment of Groundwater Quality for Use in Drinking Water and Agriculture: Tadla Plain, Morocco. *Afrique Science, 8,* 54-66.

FCAM (Federation of Agriculture Chambers of Morocco) (2018). *Diagnostic de l'Agriculture dans la Région de Tadla Azilal*. http://www.fecam.ma

Gajbhiye, S., Meshram, C., Singh, S. K., Srivastava, P. K., & Islam, T. (2016). Precipitation Trend Analysis of Sindh River Basin, India, from 102-Year Record (1901-2002). *Atmospheric Science Letters, 17,* 71-77. https://doi.org/10.1002/asl.602

Ghaffari, H., Tadayon, M. R., Bahador, M., & Razmjoo, J. (2021). Investigation of the Proline Role in Controlling Traits Related to Sugar and Root Yield of Sugar Beet under Water Deficit Conditions. *Agricultural Water Management, 243,* Article 106448. https://doi.org/10.1016/j.agwat.2020.106448

Ghaffari, H., Tadayon, M. R., Nadeem, M., Cheema, M., & Razmjoo, J. (2019). Proline-Mediated Changes in Antioxidant Enzymatic Activities and the Physiology of Sugar Beet under Drought Stress. *Acta Physiologiae Plantarum, 41,* Article No. 23. https://doi.org/10.1007/s11738-019-2815-z

Hammani, A., & Kuper, M. (2007). Characterization of Groundwater Pumping in Tadla, Morocco. In *Saving Water in Irrigated Systems in the Maghreb: The Third Regional Workshop of the SIRMA Project*. CIRAD.

Hammani, A., El Masri, A., Bouaziz, A., & Kuper, M. (2008). Enhancing Groundwater Utilization through Forage Crops in the Tadla Irrigated Area. In *Saving Water in Irrigated Systems in the Maghreb: The Fourth Regional Workshop*. CIRAD.

Hammani, A., Kuper, M., Bekkar, Y., & Zaz, H. (2006). Exploitation of Groundwater in the Tadla Irrigated Area (Morocco): Current Situation and Methodological Elements for Integrated and Sustainable Management of Groundwater and Surface Water. In

Scientific and Technical Workshop of the Project Sirma. CIRAD.

HCP (High Commission for Planning) (2014). *General Population and Housing Census 2014*.

Hirsch, R. M., Slack, J. R., & Smith, R. A. (1982). Techniques of Trend Analysis for Monthly Water Quality Data. *Water Resources Research, 18,* 107-121. https://doi.org/10.1029/WR018i001p00107

INRA (National Institute of Agronomic Research) (2002). *Research Achievements and Constraints in the Olive Sector. International Olive Seminar*. Marrakech.

IRDR (Inter-Réseaux Développement Rural) (2016). *Bulletin de synthèse n°20: Plan Maroc Vert: Key Principles and Progress of the Moroccan Agricultural Strategy*. https://www.inter-reseaux.org

Kendall, M. G. (1975). *Rank Correlation Methods* (4th ed., 202 p). Charles Griffin.

Kobry, A., & Eliamani, A. (2004). Drip Irrigation in Large Hydraulic Perimeters: Advantages and Constraints in the Tadla Area of Morocco. In *Proceedings of the Modernization of Irrigated Agriculture Seminar*. CIRAD.

Kwelde (2006). *Monitoring of Agricultural Farms in Tadla to Determine Their Performance in Groundwater Utilization*. Ph.D. Thesis, HASSAN II Institute of Agronomy and Veterinary Medicine.

Lionboui, H., Benabdelouahab, T., Elame, F. et al. (2018). Estimating the Economic Impact of Climate Change on Agricultural Water Management Indicators. *Pertanika Journal of Science & Technology, 26,* 749-762.

Mann, H. B. (1945). Nonparametric Tests against Trend. *Econometrica, 13,* 245-259. https://doi.org/10.2307/1907187

McKee, T. B., Doeskenet, N. J., & Kleist, J. (1993). The Relationship of Drought Frequency & Duration to Time Scale. In *Proceedings of the Eighth Conference on Applied Climatology* (pp. 179-184). American Meteorological Society.

McKee, T. B., Doeskenet, N. J., & Kleist, J. (1995). Drought Monitoring with Multiple Time Scales. In *9th Conference on Applied Climatology* (pp. 233-236), American Meteorological Society.

Meddi, M., & Eslamian, S. (2021). Uncertainties in Rainfall and Water Resources in Maghreb Countries under Climate Change. In N. Oguge, D. Ayal, L. Adeleke, & I. da Silva (Eds.), *African Handbook of Climate Change Adaptation* (pp. 1967-2003). Springer. https://doi.org/10.1007/978-3-030-45106-6_114

Ozkan, B., Akçaoz, H., & Karadeniz, F. (2004). Energy Requirement and Economic Analysis of Citrus Production in Turkey. *Energy Conversion and Management, 45,* 1821-1830. https://doi.org/10.1016/j.enconman.2003.10.002

PACAM (Le Portail Agricole du Crédit Agricole du Maroc) (2020). *Types of Crops and the Significance of Agriculture in Morocco*. https://www.inter-reseaux.org

Park, S. E., Marshall, N. A., Jakku, E., Dowdd, A. M., Howden, S. M., Mendham, E., & Fleming, A. (2012). Informing Adaptation Responses to Climate Change through Theories of Transformation. *Global Environmental Change, 22,* 115-126. https://doi.org/10.1016/j.gloenvcha.2011.10.003

Sen, P. K. (1968). Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of the American Statistical Association, 63,* 1379-1389. https://doi.org/10.1080/01621459.1968.10480934

Sinan, M., Boussetta, M., & El Rherari, A. (2009). Climate Change: Causes and Consequences on Climate and Water Resource. *Revue HTE, 142,* 21-30.

Slama, A., Ben Salem, M., Ben Naceur, M. B., & Zid, E. (2005). Cereals in Tunisia: Production, Drought Effects, and Resistance Mechanisms. *Sécheresse, 16,* 225-229.

Tahiri, A., Amraoui, F., Sinan, M., Bouchaou, L., Berrada, F., & Benjmel, K. (2022). Influence of Climate Variability on Water Resource Availability in the Upper Basin of Oum-Er-Rabiaa, Morocco. *Groundwater for Sustainable Development, 19,* Article 100814. https://doi.org/10.1016/j.gsd.2022.100814

Theil, H. (1950). A Rank-Invariant Method of Linear and Polynomial Regression Analysis I, II, III. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen, 53,* 386-392, 512-525, 1397-1412.

This, D., & Teulat-Merah, B. (2000). Towards a Comparative Genomics of Drought Tolerance in Cereals: Lessons from a QTL Analysis in Barley. In J.-M. Ribaut, & D. Poland (Eds.), *Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water Limited Environments* (pp, 21-25). CIMMYT.

WMO (World Meteorological Organization) (2012). *User's Guide for the Standardized Precipitation Index*.

Wright, G. C. (2000). *Irrigating Citrus Trees* (pp. 1-5). Cooperative Extension Services University of Arizona.