

The Vulnerability of Tunisian Agriculture to Climate Change

21

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21.1 Introduction

Climate change constitutes a real environmental problem, which is of concern for all the countries of the planet. Worldwide rapid changes in the weather are already happening and multiple consequences are expected but the degree of impact depends on which part of the world we are talking about (IPCC, 2007, 2013). According to the 2007 Intergovernmental Panel on Climate Change Fourth Assessment Report and the World Bank (2004), the Middle East and North African (MENA) regions are the most vulnerable to climate change, and this is an urgent issue (Osman-Elasha, 2010; Sowers et al., 2011). However, in addition to climate changes, the MENA region already suffers from weather variability; the region experiences increasingly frequent droughts and a looming water supply shortage. It is predicted that environmental stresses will increase due to climate change (Mutin, 2009; Drine, 2011). In Tunisia, besides the North African countries, the population, life, and activities are significantly linked with the climate and its fluctuation (Agoumi, 2003). The sectors on which the economy of the country is based were identified as the most vulnerable to climate change: water, agriculture, coastal, and tourism (GTZ-MARH, 2007). Two-thirds of the country is arid to semiarid, making agriculture and water supply vulnerable to the predicted climate changes.

The multiyear and recurrent episodes of drought generally affect most of the country and can lead to serious problems caused by water scarcity (Iglesias et al., 2011). The spatial and temporal changes in climatic variables relating to change have resulted in much debate and several studies are ongoing worldwide (Chattopadhyay and Hulme, 1977; Georgiadi et al., 1991; Muhs and Maat, 1993; Iglesias et al., 2004; McNulty et al., 1997; Goyal, 2004; Lindner et al., 2010; Segnalini et al., 2011).

This chapter presents a summary of some local studies used to assess the impact of climate change on the agricultural sector mainly in the semiarid region of Tunisia. It is a case study, not representative for all Tunisian microclimates and also is not applicable to every agricultural system. The aim here is to call attention to the specific vulnerabilities of a sensitive, threatened region and to contribute to a better understanding of the risks and the possible impacts of climate change on agriculture.

21.2 Tunisia's agricultural constraints

Tunisia is situated in North Africa at the connection of the western and oriental Mediterranean Sea between longitudes 7° and 12° East and latitudes 32° and 38° North. Covering an area of 164,000 km², it is characterized by a pronounced climatic gradient from north to south as result of the general orientation of the main reliefs and its geographic position. Indeed, it is influenced in the north by the Mediterranean Sea, in the south by the Sahara, and in the center the combined effect of these two.

21.2.1 Climate

The northern area, profiting from the Mediterranean climate, is characterized by warm and dry summers and mild and relatively rainy winters, with an average rainfall ~600 mm/year. The center is semiarid to arid and is characterized by relatively hot temperatures and modest precipitation, between 200 and 400 mm/year. The rest of the country has a dry desert climate, characterized by hot temperatures as well as a large volume of irregular precipitation rarely exceeding 100 mm (Figure 21.1). Annual evaporation varies from 1300 mm to even more than 2500 mm, respectively, from the north to the south (Kallel et al., 2012). In addition, Tunisia experiences drought periods that can be generalized for the whole country or restricted to one or some regions. The drought duration and its intensity are variable in space and in time (Louati et al., 2007; Louati and Bucknall, 2010).

21.2.2 Water resources and distribution

Tunisia is a water-stressed country because most of it is semiarid to arid, in addition to episodic droughts; this makes water resources scarce. The World Bank warned in 2004 that Tunisia is one of 17 countries where water resources will be an “absolute rarity” by 2025. From ancient times, Tunisia's water and soil were considered valuable and received special attention to ensure their sustainability. Ancient civilizations that succeeded in the country developed various soil and water conservation techniques and the successful ones so far continue to be used. It is mainly water collection systems and soil conservation through various methods that are adapted to the environmental conditions.

The mean yearly precipitation in Tunisia is estimated to be 36 billion m³. The available water resources of 4.8 billion m³ are divided into 2.7 billion m³ surface and 2.1 billion m³ groundwater. Being aware of the water scarcity problem, Tunisians have focused considerable effort on developing all resources; actually, more than 85% of the water resources have been mobilized using several means: dams (29), hill dams (223), check dams (812), deep wells (5000), and shallow wells (95,000) (Hamdan, 2007; Horchani, 2007; Mekki, 2009). The geographical distribution of rainfall often involves major imbalances between the north, sometimes relatively well watered, and the highly arid south. Precipitation is highly variable in space and time at monthly or yearly levels. The mean average rainfall ranges from less than 100 mm in the extreme south to more than 1500 mm in the extreme northwest (Thabet et al., 1994).

Water resources are unevenly distributed across the country. Indeed, the northern region ranks first with 60%, followed by the south (22%), and finally the center (18%). Although, the northern regions occupy only 17% of the total area of Tunisia, 81.2% of surface water resources are located in the north. On the contrary, the south has the most groundwater, particularly in deep-lying aquifers. The center is the poorest region for water resources, both in terms of quantity and in its

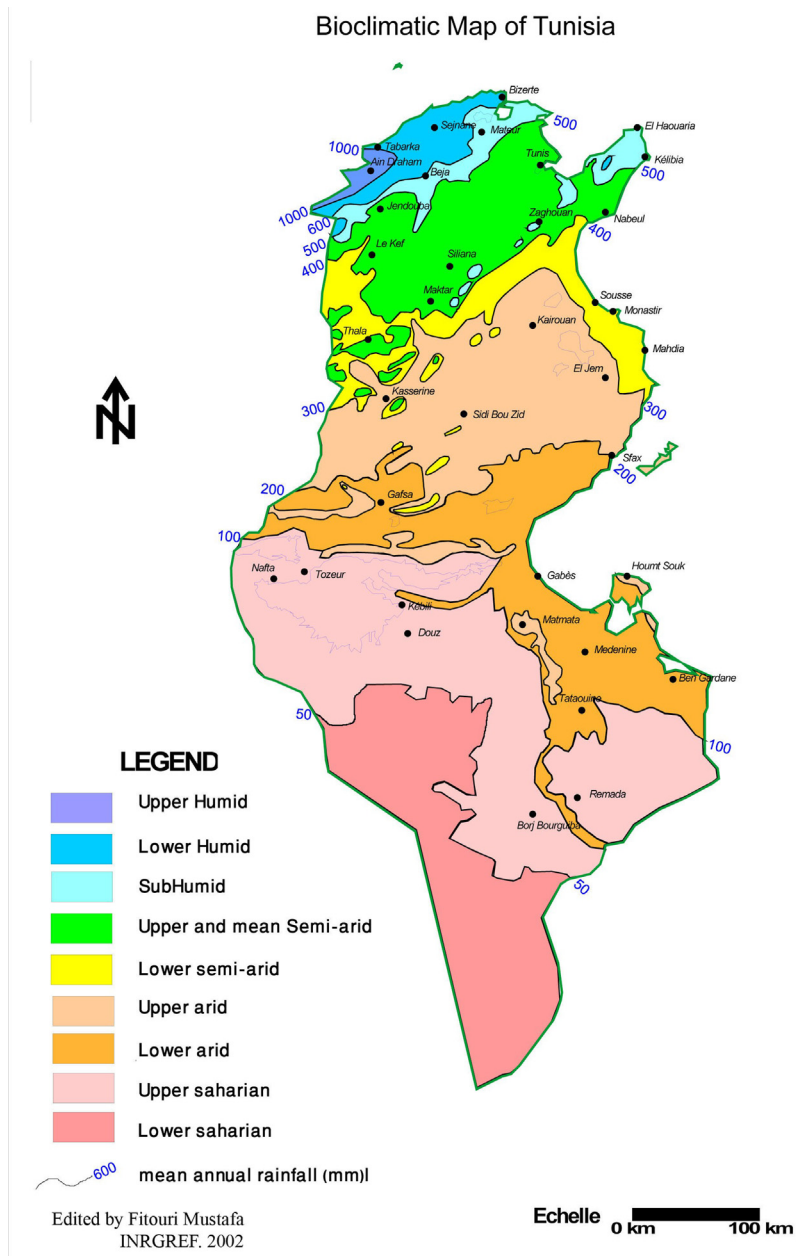
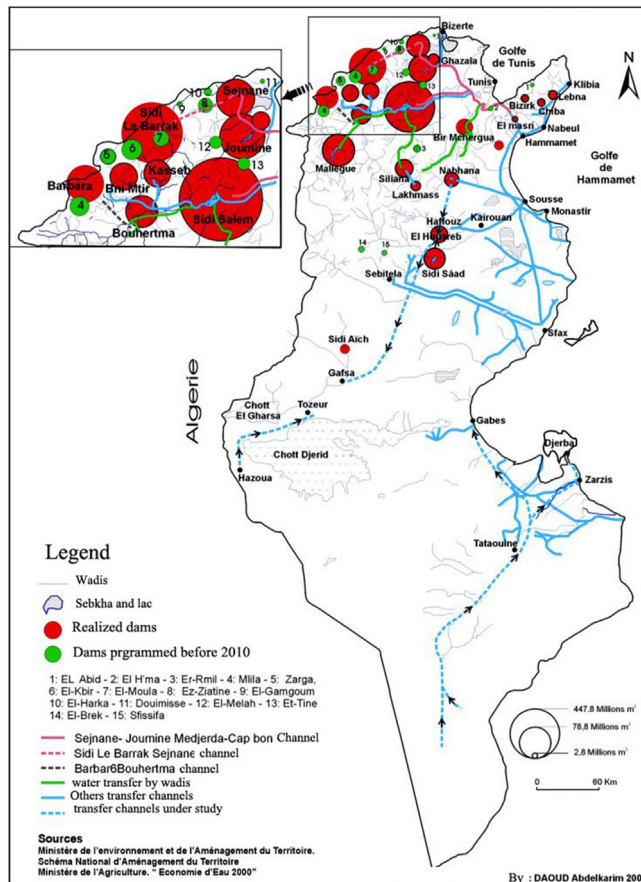


FIGURE 21.1

Tunisia rainfall distribution.

**FIGURE 21.2**

Water mobilization and transfer in Tunisia.

quality (Hamdan, 2007). The inequalities between regions make water management more difficult and explain the need to transfer surface water from the north to the center and south in order to improve the drinking water supply and ensure equity between regions (Figure 21.2).

The problem of inequality of water distribution is as old as the history of the country. Indeed, by 130 AD and through the ingenuity of the emperor Hardian, the Roman (who occupied Tunisia for nearly five centuries) tried to solve the problem of water supply in the region of Carthage by constructing a huge 132 km aqueduct linking the city to the sources of Djebel Zaghouan, a real water tower (Figure 21.3). With the ancient aqueducts restored in 1860, until 1905 Zaghouan remained the main source of drinking water for the city of Tunis. Likewise, in the early eighth century, the aghlabides supplied the town of Kairouan (center of Tunisia); they transferred the groundwater and stored it in big basins (Figure 21.4). The concern about water persists because it is required for development in all social and economic sectors (Ben Abdallah, 2007).



FIGURE 21.3

The Roman aqueduct that transferred water over the Zaghouan to the city of Carthage.



FIGURE 21.4

Aghlabid Basin in Kairouan.

Besides water scarcity, its quality constitutes an additional problem because the salinity of most water resources exceeds the international threshold for health and agricultural uses (30% with a salinity of more than 4 g/L). In fact, due to the high salinity level, only a modest proportion of the available water meets the standards for drinking water.

The problem of salinity is not as pronounced for surface water, where its salt content is low to moderate (except for some tributaries of the Medjerda River), as for groundwater, which is significantly affected. Indeed, 26% of surface resources, 91.6% of shallow aquifers, and 80% of deep aquifers exceed the salinity standard of 1.5 g/L (Mamou and Kassah, 2000). What is disquieting is that salinity continues to increase as a result of overexploitation of groundwater and intrusion of the seawater. In addition, it is thought that climate change may make the situation worse through increasing evaporation and the rising sea level.

21.2.3 Agricultural characteristics

In Tunisia, the agricultural sector occupies a first-rate place in the national economy and plays an important role in regional and social development. However, it consumes the most water (83% of total available resources). As noted by [Horchani \(2007\)](#), 2100 million m³ of water are used for irrigation with an average consumption per ha of approximately 5500 m³/year.

Water deficit and drought represent a permanent risk for Tunisian agriculture and makes production variable and highly correlated with rainy events. Indeed, the smallest part of the irrigated area (<10% of total cultivated land) constitutes an important pillar of the agricultural economy because it provides 35% of the production, 20% of the exports (of the sector), and 27% of the workforce. In addition, it plays a social role by decreasing exodus, as it provides a regular income that can be twice or may even be three times that of the rain-fed farming area ([Horchani, 2007](#)). Agricultural production in Tunisia is extensive and the main products are olive oil, citrus fruit, cereals, dates, and several horticultural products.

The division of cultivated land by major crops shows the importance of cereals, mainly wheat and barley, followed by tree crops, which together cover ~87% of the total cultivated area—43% cereals, 44% tree crops (mainly olives); the remaining 13% is divided between forage crops (7%), vegetable crops (3%), legumes (2.5%), and others (0.5%) ([Thabet et al., 1994](#)). Cereals followed by olive trees are the most important crops grown under rain-fed conditions. As they are the main source of food calories and the common basis of all diets, both urban and rural areas and for different income strata, cereals are considered one of the most important agricultural sectors of Tunisia's economy. Thus, cereals, mainly wheat, are considered a vital product. On the other hand, 97% of the cereals are cultivated under rain-fed conditions. ([Mougou and Ben Salem, 2003](#)); therefore production is very variable because essentially it depends on rainfall ([Mougou et al., 2008](#)).

The olive tree, widely present in the Tunisian landscape, constitutes one of the most important and traditional agricultural activities. This sector, which marks the history of Tunisia's rural population, covers more than 1.6 million ha, representing 79% of total surface area of fruit trees and close to 35% of arable land. These trees, which are spread out all over the country under different bioclimatic conditions from the north to the south, constitute an important part of the Tunisian agriculture and play a leading socioeconomic role.

In addition, the olive tree and its products make up an integral part of the daily life of Tunisians, as material as spiritual. It needs to be emphasized that olive oil contributes more than 60% to total food exports. The number of olive trees in Tunisia is estimated to be 60 million (29.5% in the north, 45.3% in the center, and 25.2% in the south). Known for its hardiness, the trees also can be found in poor marginal lands, even those threatened by erosion and desertification. The planting density of olive trees varies between regions and is generally adjusted according to mean annual rainfall. The tree is present mostly in monocultures and is rarely integrated with other fruit species. However, olive trees can be located near some vegetables or cereals especially in the center and south where the trees are often widely spaced.

The status of this crop as a sacred tree, revered by generations, makes its production contribute to the income of more than 200,000 farmers and constitutes a main activity for 30% of them. In addition, approximately a million families are employed in the various functions of the olive—oil pathway (e.g., mechanization, size, crop, transport, stocking, marketing). The social attachment of farmers to olive trees has its origins in the durability of the crop, marked by its history as being the

main agricultural activity of the rural population for several generations. Because of the significant attachment of the population to it, Tunisia is ranked as one of the largest producers and exporters of olive oil, providing more than a fifth of world exports.

The olive tree has a great capacity to adapt to different climates and may also valorize dry regions. Nevertheless, it remains sensitive to water deficit. This Mediterranean tree is able to withstand drought by the strong osmotic pressure of its root system; it is able to profit from low humidity through its capacity to close stomata to decrease evapotranspiration when the air pressure evaporation increases. However, prolonged drought is damaging to this crop. The olive tree can support about 50% of yearly water deficit; if the deficit is experienced for a second year, the tree endures the drought only in marginal zones.

According to the national strategy of adaptation (GTZ-MARH, 2007), climate modifications in Tunisia may have serious consequences on water resources, ecosystems, and agrosystems, mainly on the olive and cereal sectors. With the aim of assessing the sustainability of this important crop under future climate change conditions, the studies have been carried relative to the vulnerability of this sector.

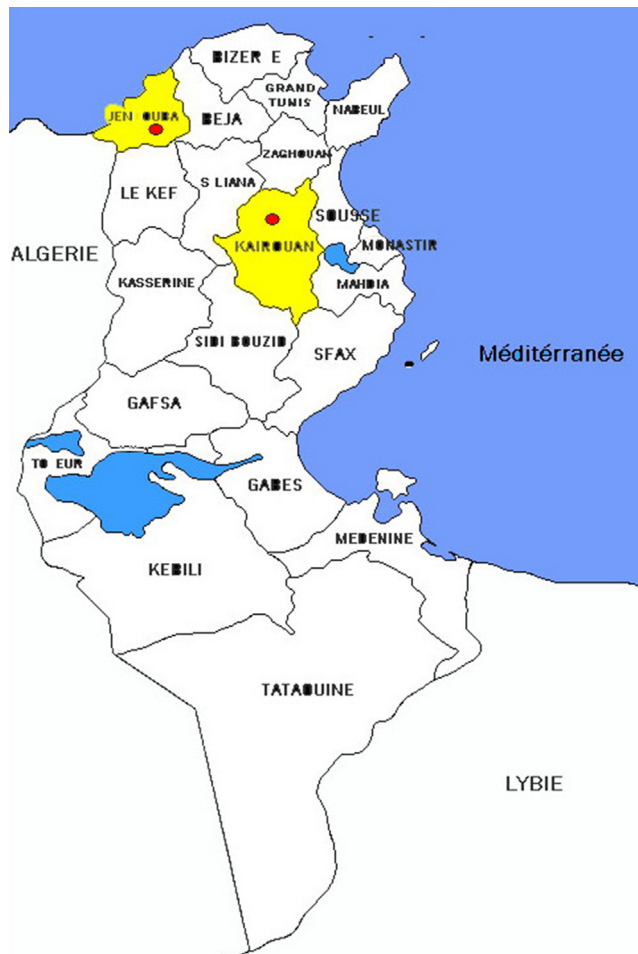
21.3 The impact of climate change on wheat production in Tunisia's semiarid region

The central region of Tunisia contains the most important area for olive cultivation and rain-fed cereals. Unfortunately, it is the most vulnerable region because of excessive climatic variability and its mainly rain-fed agriculture. In this region, water deficit and drought constitute an ongoing risk for agriculture. Rainfall is characterized by an important yearly variability and by its scarcity; consequently, production varies widely (Bergaoui, 2010). In severely dry years (deficit >50%), drought persists more frequently in the south and the center than in the north. The temperatures are moderate; however, very hot conditions are frequent and may occur from May to September. The average temperature in August is ~30°C and the maximum temperature can reach 45°C. The high temperatures may affect crop production, especially when they occur at a critical stage of the growing.

In addition, water resources are limited and a majority of it is of bad quality (>4 dS/m). This region is very representative of a vulnerable agricultural system and facilitates an understanding of how Tunisia's crops may be affected by climate change. This is why the majority of the studies concerning climate change's impact on agriculture have been done in this region; two were done with the aim of assessing the effect of future climate change on wheat production (Figure 21.5).

Lhomme et al. (2009) simulated durum wheat production under climate change conditions for two regions: Jendouba and Kairouan, respectively situated in the north and the center of Tunisia; they are characterized by a typical Mediterranean climate. Although they are not very far apart, a significant rainfall gradient exists between the two regions, essentially due to the ridge of mountains that separates them (Sakiss et al., 1991).

A simple crop model was used for the simulation of the 2071–2100 climate projection. The ARPEGE atmospheric model, developed by Météo-France (Déqué, 2007), has been used for the A1B scenario (IPCC scenario). Mougou et al. (2011) assessed the impact of projected climate change on wheat yield and the wheat growing season duration using the IPCC, 2001 scenarios of temperature increase: IS92c (+1.3°C), IS92a (+2°C), IS92e (+2.5°C), and (+4°C).

**FIGURE 21.5**

The two regions considered in the studies of [Lhomme et al. \(2009\)](#) and [Mougou et al. \(2011\)](#).

The IS92a and IS92c scenarios were used as input for MAGICC/SCENGEN simulations ([Santer et al., 1990](#); [Wigley and Raper, 1992](#); [IPCC, 1996](#); [Raper et al., 1996](#); [Hulme et al., 2000](#)). The impact of climate change on wheat production has been evaluated with the Decision Support System for Agrotechnology Transfer (DSSAT) crop model using previous simulation findings. The results showed a disparity in production according to the study region and kind of scenarios used. [Lhomme et al. \(2009\)](#) showed probable decreases in crop productivity in Jendouba (northern region with semiarid climate) but an increase in Kairouan (the center region with arid climate). However, [Mougou et al. \(2011\)](#) showed that in the Kairouan region, when applying the scenario of combined effect of temperature increase (+1.5°C) and rainfall decrease (−10%), wheat production can fall by −48%.

It has been noticed also that the wheat growing season varies in relation to the increase in temperature. Mougou et al. (2011) predicted that by 2100 in the Kairouan region, the wheat growing season may be shortened by 10, 16, 20, and 30 d, respectively, for 1.3°C, 2°C, 2.5°C, and 4°C temperature conditions. Lhomme et al. (2009) found similar results, as the wheat crop cycle mean duration was reduced by approximately 25 d in the Kairouan region.

The impact of growth cycle shortening can affect yield quantitatively as well as qualitatively as a consequence of damages sustained during flowering and grain filling. Therefore, in the future it may be better to sow earlier (one month before the current planting date) because of more favorable water conditions during early autumn (Lhomme et al., 2009). According to Mougou et al. (2011), wheat yield is significantly correlated with yearly total rainfall especially during the farming season, September to April, with March rainfall being of particular importance.

Previous analysis of rainfall data showed that during the last century there was a highly correlated relationship between autumn rainfall quantities and the yearly precipitation amount. This can be used as a pertinent index to determine whether the year is drought prone or likely to be rainy. In fact, by a mean of 70%, drought years have started with a dry autumn. At the regional scale, this percentage is 78% and 90%, respectively, for the north and both the center and the south. Louati et al. (2005) noted that precipitation during the autumn represented 40% of the mean yearly quantity.

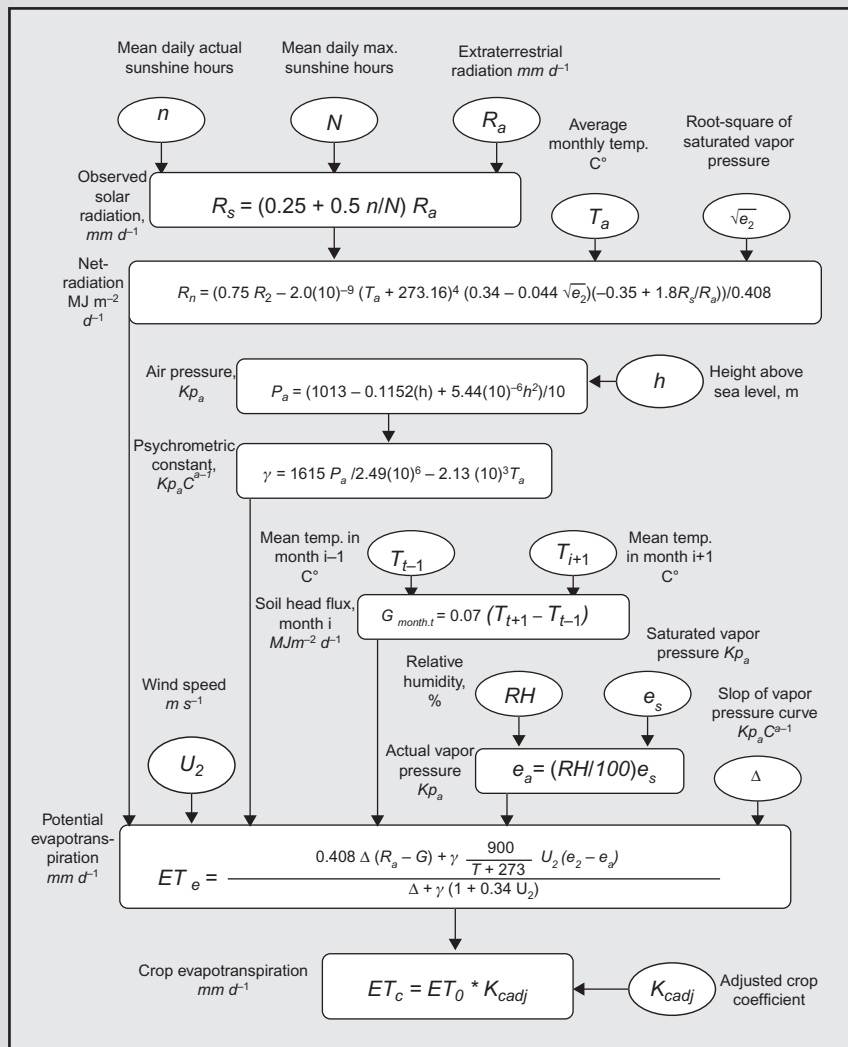
21.4 Climatic change parameters that influence evapotranspiration in central Tunisia's coastal region

As quoted in the World Bank report in 2004, Tunisia is expected to experience water scarcity by 2025. Due to population growth, rapid urbanization, and agricultural and industrial development, the country may face a complex situation because of the increase in water demand by the several users, and the conflicts between them may be more acute then. Under such a situation, any supplemental increase in water demand as a result of global warming probably will put tremendous pressure on existing water resources. The warming of the climate may modify water availability by changing precipitation and evaporative demand, and any changes in the climatic parameters due to rising temperatures are expected to affect evapotranspiration and crop water requirements. Many studies have shown a decrease in the evapotranspiration trend over the past decade in many places (Gao et al., 2007; Han et al., 2012). Others have reported the opposite phenomenon: an increase in the evapotranspiration trend (Gao et al., 2007; Chang-yu et al., 2006).

Mougou et al. (2011) studied the Kairouan region for the impact of temperature increases on reference evapotranspiration (ET_o). The results showed, respectively, an increase in ET_o by 3.1%, 4.5%, and 9.4% by a temperature increase of 1.3°C, 2°C, and 4°C compared to actual values. However, the studies of Xu et al. (2006a,b) and Ohmura and Wild (2002) indicated that the ET_o trend was not determined by temperature alone. That is why researchers try to study the impact of climate change on temporal trends of evapotranspiration and the climatic parameters influencing it (Mansour et al., 2010) (see Box 21.1).

The Penman–Monteith methodology described in the FAO Irrigation and Drainage Paper N°56 (Allen et al., 1998) has been used for the calculation of ET_o. The study evaluated a coastal

BOX 21.1 CALCULATION OF CROP WATER REQUIREMENTS USING FAO METHODOLOGY

Source: Adapted from [Hokam \(2002\)](#).

region in the center of Tunisia (ChottMeriem: 35°55N lat, 10°34E long, 15 m alt). Daily meteorological parameters (temperature, humidity, wind speed, and sunshine hours) for 33 years (1973–2005) were used (Figure 21.6). The temporal trend of the climatic parameters were analyzed using the Mann–Kendall trend test (Mann, 1945; Kendall and Gibbons, 1990; Gocic and Trajkovic, 2013). The sensitivity of ETo has been studied in terms of the change of most of the climatic parameters involved.

The Kendall test used to determine the annual statistics showed that there is no statistically significant ETo trend because we obtained an unexpected clear trend evolution for the reference of



FIGURE 21.6

Study region (ChottMeriem).

ET_o, like those shown in several previous studies cited by Gao et al. (2007) and Chang-yu et al. (2006). We tried to understand more about the cause of this result by analyzing the trend of all climatic data on which reference evapotranspiration depends.

The reference evapotranspiration equation (i.e., Eq. 21.1 in Box 21.2) is the sum of two terms, known as radiation and aerodynamics, as shown in Eq. 21.2. The temporal study of each part alone shows a significant, respectively, increasing and decreasing trend of ET_{rad} and ET_{aero}. This opposite finding relevant to the two terms explains why a significant trend of the reference ET_o was not detected. To understand more about the cause of this result, the trend of all climatic data on which the reference evapotranspiration depends was analyzed. The study showed a significant trend of temperature; however, maximum and minimum temperature does not evolve in the same way. A significant temperature trend was detected during spring and summer periods (hot season), especially for maximum temperatures.

A highly significant trend for the air vapor deficit, which appears especially from May to June, was detected. The wind speed showed a significant decreasing trend during the year. Even if a similar trend was found (Chang-yu et al., 2006; Jin-liang et al., 2012), relating this decreasing trend of the wind speed to the climate change phenomenon must be considered more carefully.

BOX 21.2 THE REFERENCE EVAPOTRANSPIRATION EQUATION

The ET_o can be expressed, according to Allen et al. (1998), as:

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (21.1)$$

where

ET_o = the reference evapotranspiration (mm day⁻¹)

ET_o was defined as the evaporation of an extension surface of green grass of uniform height (0.12 m) that was actively growing and adequately watered, having a surface resistance of 70 s m⁻¹ and albedo of 0.23:

Rn = net radiation at the crop surface (MJm⁻² day⁻¹)

G = soil heat flux density (MJm⁻² day⁻¹);

T = mean daily temperature at 2 m height [°C]

U₂ = wind speed at 2 m height [m s⁻¹]

e_s = saturation vapor pressure [kPa]

e_a = actual vapor pressure [kPa]

e_s - e_a = saturation vapor pressure deficit [kPa]

Δ = slope of vapor pressure curve [kPa °C⁻¹]

γ = psychrometric constant [kPa °C⁻¹] = 0.665 × 10⁻³ P

Equation (21.1) can be divided into two terms, as follows:

$$ET_o = ET_{rad} + ET_{aero} \quad (21.2)$$

With

$$ET_{rad} = \frac{0.408\Delta(Rn - G)}{\Delta + \gamma(1 + 0.34U_2)} \quad (21.3)$$

$$ET_{aero} = \frac{\gamma \frac{900}{T+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (21.4)$$

Because such a change in wind speed also can be the result of environmental changes around the climatic station, such as buildings rising and or tree growth, we think that this is the most realistic hypothesis. If it is the case, this may induce an error and give an incorrect idea about the ETo as consequence on the effect of future climate change on water resources. This remark is also valid for the other climatic parameters because, for climate change studies, a long series of data is needed; should the environment around the old climatic station have changed, this can influence the credibility of the measured data. The sensitivity analysis test showed that the most influential parameters on ETo are, respectively, net shortwave and longwave radiation, with the actual vapor pressure and the maximum temperature.

21.5 Conclusion and future prospects

In a country poor in natural resources, such as Tunisia, agriculture plays a vital role in its economy. However, agriculture in Tunisia is vulnerable as a result of several interconnected causes. The climate variability (in time and space) combined with the aridity of most of the country means that water resources are scarce, with a deteriorated quality in most regions. Not to forget the soil resources problem, because only 47.3% of the land's soils are fertile to moderately so, and annual soil loss represents 1%. In addition, 55% of the total area is potentially agricultural land (9 million ha); however, 50% of the irrigated land is affected by salinity (10% significantly affected). Tunisia's agriculture produces mainly rain-fed crops and the agricultural population is made up of small farmers. Climate change, as predicted, may affect the sector and lead to important modifications of practices, mainly to enhance water availability, seeing that a water conflict is likely to occur between the different users in the future.

With regard to regional specificity whether at a continental scale or for the country itself, further study is necessary in order to develop future climatic scenarios and prepare a sustainable adaptation plan for the country. As reported by [Smit et al. \(2000\)](#), the extent to which the several sectors related to climate (e.g., ecosystems, agriculture, health, sustainable development) are at risk due to anticipated change; this depends both on the magnitude of the phenomenon and the adaptation capacity of the impacted system. Planning for a sustainable agriculture can be undertaken using the statistical trend of climatic factors. Thus, more research programs to facilitate understanding should be done to determine what is really happening (regional climate). This needs to be followed by evaluating what kind of potential there is, and what the available adaptation possibilities are.

Researchers have to know, by an objective analysis of the actual situation, the untapped potential and discover how bad things are in order to get the best value out of existing environmental conditions; this is necessary before improvements can be more efficient and actions can be taken to implement interventions. Thus, before proposing new solutions that may be costly, further studies must highlight a better way to utilize existing resources, mainly the underexploited or inappropriately exploited, to face the climate change. It is also important to take into account the farmer's strategies and encourage the participative approach in the aim of improving traditional methods and facilitating adaptation of new technologies.

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