CHAPTER 3

Water scarcity and food security: A global assessment of water potentiality in Tunisia

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ABSTRACT: In arid countries, where water resources are scarce, the various aspects related to water management and water uses are interlinked at the national scale. Tunisia is fairly advanced in water resource planning and management and its scarce hydraulic resources are almost entirely mobilized. The country is therefore obliged to apply new concepts, new paradigms, to optimize the use of different types of water resources. A comprehensive model for water balance of Tunisia has been developed and adjusted from data at the national scale. This model takes into account all of water resources: the withdrawal water *Blue Water*, the Equivalent-Water of the rainfed agriculture *Green Water*, and the net contribution in Equivalent-Water of the import-export food balance *Virtual Water*. The model is used in order to simulate three scenarios for the prospective horizons 2025 and 2050. The first two scenarios are based on a traditional vision of the water resource which considers only the withdrawal water management *Blue Water*. The third scenario considers the total water resource potential involved in food production. The simulations indicate that the improvement of food safety will depend, in the future, on the capacity to manage all the available water resources, in particular by improving the potential of rainfed agriculture.

Keywords: water resources, water management, water balance, green water, blue water, virtual water, Tunisia

1 INTRODUCTION

The recent increases in prices of basic food products (cereals, rice, vegetable oil, etc.) have revived the debate on the sensitive issue of food security in importing countries. These countries suffer the effects of these increases on their trade balances that generate, in the poorest countries, real food crises. This situation challenges traditional patterns of agricultural development and food security. In fact, the spectacular results of the green revolution and its impact on agricultural production have led to a widespread acceptance, which is to admit that the use of intensive irrigated agriculture is essential to meet the food challenge.

In arid and semi-arid countries the scarcity of water resources is a highly limiting factor for increased food production. When water resources are limiting agricultural production, food importation seems to be a way which is used consciously or unconsciously to fill the water deficit. One speaks about *Virtual Water*. This concept means that the importation of foodstuffs is similar to importing an amount of water equivalent to the volume required to produce it locally (Allan, 1998). In general, the significant contribution of *Virtual Water* is not directly taken into account in water resources planning and is not accounted for characterizing water stress situations.

On the other hand, the Equivalent-Water of the agricultural production related to rainfed crops corresponds to the volume extracted by plants from water contained in the soil (*Green Water*). The amount of *Green Water*, often much more important than water used in irrigated agriculture, takes an important part in *Virtual Water* trade (cereals, oil, etc.) and its contribution is often decisive. Liu (2007) estimated that over 80% of the water involved in agricultural production comes from rainfed agriculture, which accounts for 90% to foodstuffs trade. The quantification of the trade in *Virtual Water*, taking care to distinguish between the water that comes from irrigated agriculture and trade from rainfed agriculture, is very instructive. It helps to clarify the relationship between agricultural and water policies and their impacts on the management and use of water resources.

Before progressing in the analysis, we must first note that the direct needs (urban, industrial and tourism) are generally moderate. Some authors like Gleick (1996) and Warner (1995), have tried to quantify the *Basic Water Requirements* (BWRs). BWRs define the minimum quantities of water needed to cover the basic water uses of a person: drinking, food preparation and hygiene. All these uses account for only relatively small water quantities estimated at 18 m^3/hab/yr (Gleick, 1996). The needs for basic water represent only a small part (few percent) of the overall water demand. In contrast, the part of water demand involved in foodstuffs production is relatively high.

Many recent works have been devoted to the evaluation of the quantity of water required in foodstuffs production (Hoekstra, 2003; Oki *et al*., 2003; Renault & Wallender, 2000). In spite of their disparities, data resulting from research provide edifying information on the relation between water and foodstuffs production. It appears that the amount of water needed for food production depends greatly on the nutritional mode. Disregarding the origin of water used in agriculture, the production of 1 kg of cereals needs approximately 1 m^3 of water, while more than 20 m^3 are necessary to produce 1 kg of beef (Oki *et al*., 2003). As a result, the water needed for food production is about 2.5 m^3/day per capita for a diet with low animal product intake, e.g. in North Africa; it exceeds 5 m^3/day per capita for a diet with high animal product intake such as in Europe or in the USA (Renault & Wallender, 2000).

The important quantities of water involved in food production indicate that a full understanding of water issues should consider the structure of agricultural production. Adequacy or shortage of water resources depends mainly on the role that society assigns to irrigation and the place it is supposed to play in development policies in general and in agricultural policies in particular. The concept of the *Water Footprint* introduced in the early 2000s suggested a comprehensive review to assess the potential of all water resources. The annual freshwater availability, which corresponds to the sum of *Green Water* availability and *Blue Water* availability, is equal to the total precipitation above land. This includes all resources used by the ecosystem (Besbes *et al*., 2002; Hoekstra & Hung, 2002; Chapagain & Hoekstra, 2004; Hoekstra & Chapagain, 2007).

In an analysis of water resources through the globe, De Marsily (2006) specified the significant contribution of international food trade in water supply-demand adequacy, and drew attention to the important role of rainfed agriculture in food safety. This new presentation of water resources should be used today for planning water resources development and allocation in arid countries by explicitly taking into account all kinds of water (*Green, Blue* and *Virtual Water*) and all the current needs.

In previous papers we proposed a comprehensive water balance for Tunisia (Chahed *et al*., 2007; 2008). In this balance one considers all kinds of water resources, e.g. *Blue Water*, *Green Water* as well as the contribution of the agro-alimentary trade balance *Virtual Water*. The adjustment of this balance has led to develop a model that compares the total of water demand in Tunisia with the potential of all water and soil resources.

Based on a holistic water vision, we developed a first prospective investigation for the horizon 2025 using a global water resource model (Besbes *et al*., 2007; Besbes *et al*., 2010). We propose, in the present work, to use this model in order to simulate scenarios for two prospective horizons (2025 and 2050). In these scenarios we attempt to assess the impacts of changing water needs, including food demand. These scenarios are then tested with different modes of management and development of all water resources including water resources involved in rainfed agriculture *Green Water*. Tunisia is an interesting example that lends itself well to this kind of exercise: it is a semi-arid country where water resources, which are structurally limited, have been fully mobilized and completely regulated. Tunisia is therefore required to find solutions to the problem of limited water resources by exploring the full development potential and enhancement of all water resources.

Figure 1. Tunisia.
Source: UNESCO (2009).

But first let's give an overview on the state of water resources and how Tunisia has addressed the question of future water use. Tunisia is situated in North Africa, bounded on the West by Algeria and on the Southeast by Libya; and bordered on the North and the East by the Mediterranean Sea along 1,200 km of coastline and on South by the Sahara (Figure 1).

Tunisia, which occupies an area of 164,420 km^2, has an uneven relief ranging from the mountainous regions in the Northwest to the desert regions of the Southeast through the plains of central Tunisia, the mountainous regions in the Northwest, the plains of central region and the desert in Southeastern regions. The population, estimated at 10.2 million in 2007, has nearly doubled in the space of 35 years, and should reach and stabilize at 13 million people by 2040 (INS, 2005). The rural population accounts for 35% and there has been rapid urbanization (expected at 75% in 2025) due to preferential migration to coastal cities.

In Tunisia, as in many other water scarce countries, the main water-resource management objective has been to provide sufficient quantities to municipalities, industry, tourism and agriculture by developing surface water and groundwater. Tunisia has positive results in terms of economic growth and productivity which have led to a significant improvement of living conditions. The country has reached respectable levels of GDP per capita and good social welfare, as evidenced by large coverage of water supply and sanitation in urban and rural zones. But at the same time, these performances are the origin of new contradictions between the imperatives of economic productivity which has been constantly increased, especially in agriculture, and the necessity of conserving natural resources, water and soil, scarce and fragile. Industrial development and urbanization also have important impacts on the development of water resources.

2 THE WATER RESOURCES OF TUNISIA

Spanning seven degrees of latitude, Tunisia offers a wide variety of hydro climatic regimes: a) sub humid in the North; b) semi-arid in the Northwest and in the Cap-Bon; c) arid in the central region; and d) hyper-arid in the desert region covering the entire South of the country. In the North, the Atlas mountains oriented SW-NE (between 500 and 1,500 m of altitude) delimitate the most fertile plains of the country. The main river, the Oued Medjerda, is now entirely controlled by a series of large dams. It crosses the North region from West to East and discharges in the Northern Gulf of Tunis.

The rainfall distribution is related to climate, to the disposition of relief and to the direction of prevailing NW winter winds. If the average rainfall reaches 1,500 mm/yr in the far North part of the country, it is about 500 mm/yr in the North, 250 mm/yr in the central regions, and it rarely exceeds 50 mm/yr in the extreme Southern regions located in the Sahara (Figure 2). The estimated rainfall in Tunisia amounted to 36,000 Mm^3/yr, corresponding to an average rainfall height of 220 mm/yr.

2.1 *Surface water resources*

For the three major natural regions, the contributions from surface water are as follows: a) the North, which covers 28% of the land area, provides regular and significant inputs into surface water evaluated at 2,200 Mm^3/yr, or 81% of the total potential of the country; b) the Center covers an area of 28% and has irregular resources estimated at 320 Mm^3/yr or 11% of the total surface water; c) the hyper-arid South, covering an area of 44% with only 180 Mm^3/yr or 8% of the total surface water. The national potential of surface water is estimated at 2,700 Mm^3/yr on average, of which 2,100 Mm^3/yr can be easily mobilized by dams and small lakes; the remaining part (600 Mm^3/yr) is more difficult to mobilize and requires small hydraulic structures like spates, reservoirs, cisterns . . .

Surface water resources have a very high inter-annual variability, with a minimum of 780 Mm^3/yr (observed in 1993–94) and a maximum of 11,000 Mm^3/yr (in 1969–70). The ratio of max/min of annual flows varies between 9 in the North and 180 in the South (Frigui, 2005). Moreover, the quality of surface water varies greatly by region: while in the North, 82% of surface water has salinity of less than 1.5 g/L, the proportion with this salinity is only 48% in the central region of the country and 3% in the South (Kallel, 1994).

In 2008, Tunisia had 27 large dams (height above 15 m), 200 small dams and 800 small lakes. All these water infrastructures can mobilize 1,800 Mm^3/yr.

2.2 *Groundwater resources*

Groundwater is related to the structure and geometry of geological formations. In Northern Tunisia, where strata are strongly pleated, there are many small layers, which might grow in the plains. In return, the central region of Tunisia is characterized by an important development of basins containing large aquifers which can be up to hundreds of meters thick.

The South of Tunisia is dominated by the Saharan platform where large aquifers extend over hundreds of thousands of km^2. Tunisia shares with Algeria and Libya these gigantic reserves, which are only partially usable and weakly renewable.

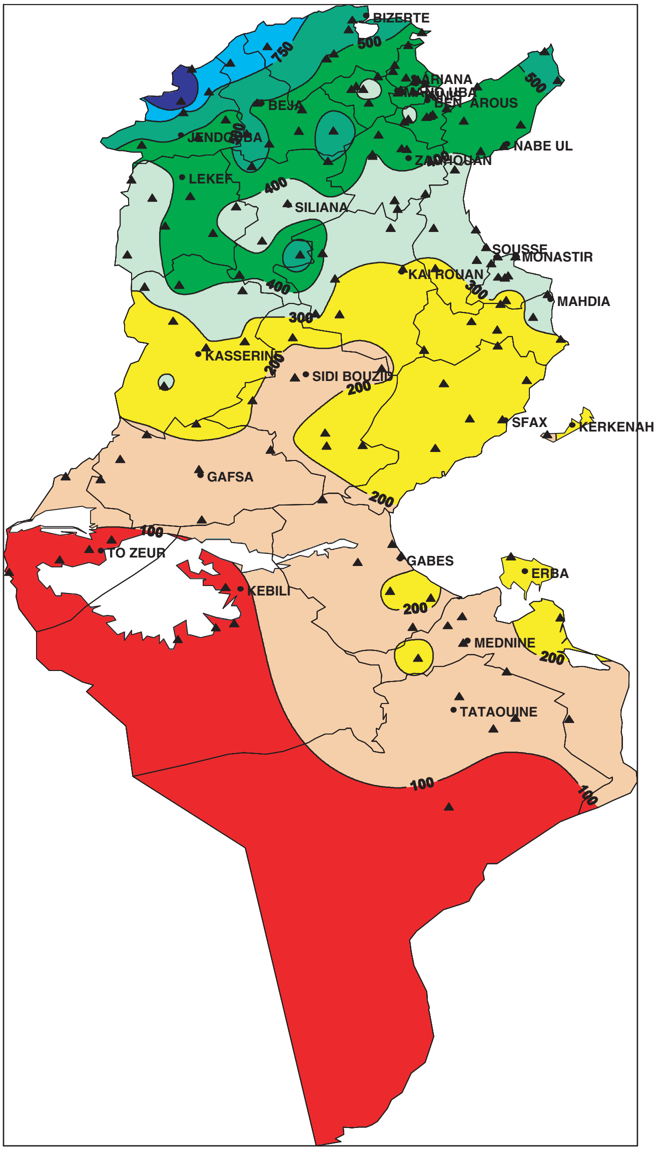

Figure 2. Mean Isohyets (mm/yr) and national rainfall Network.
Source: Frigui (2005).

Tunisian hydrogeologists conventionally distinguish between shallow aquifers exploited by large diameter dug wells and deep aquifers exploited by several hundred meters drillings. The exploitable groundwater resources of Tunisia are estimated at 2,150 Mm^3/yr (Hamza, 2006) [750 Mm^3/yr for shallow aquifers, 1,400 Mm^3/yr for deep aquifers]. Abstracted volumes in 2005 are estimated at 1,950 Mm^3/yr [800 in shallow aquifers, 1,150 in deep aquifers], which represent an exploitation index [ratio Exploitation/Resources] of 90%. Figure 3 shows how this index has changed over the past 15 years, with a steady increase from 1990 to 2001, then a stabilization between 2001 and 2005, although this is still too short a period to be considered significant.

However, the value of the exploitation index at the national scale hides huge discrepancies at two levels. First, between shallow and deep aquifers: while the index by deep wells is about 80%,

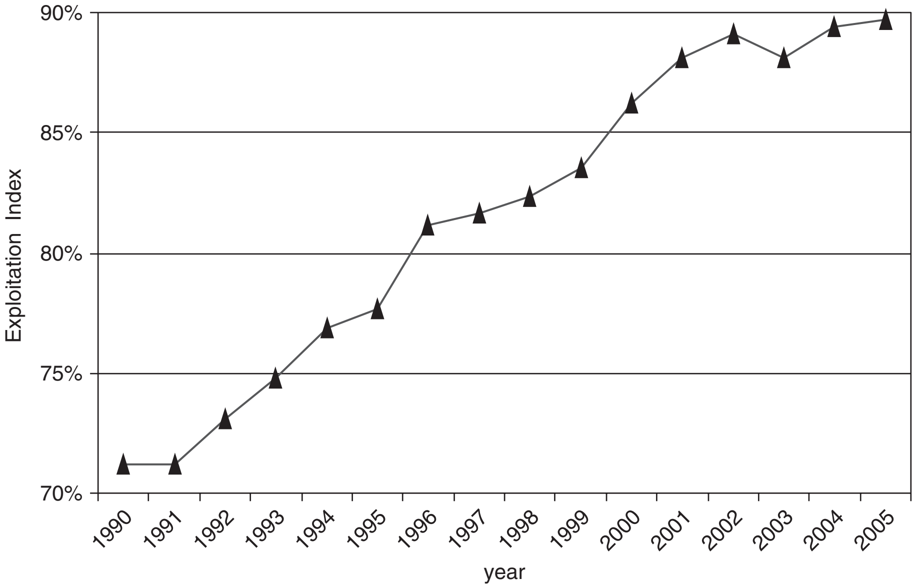

Figure 3. Groundwater exploitation index from 1990 to 2005.

it reaches 108% for shallow wells. Then, at the regional level: of the 24 regions (governorates), five of them account for almost 50% of national resources, and 60% of water mobilization. The above observations are based on the assessment of exploited resources, but the assessment of the water balance at the regional level is subject to significant uncertainties. It is therefore necessary to confirm these estimates and trends using measurable parameters, the most accessible and significant being the piezometric level series.

In this regard, regular observation of groundwater level began in Tunisia more than 60 years ago. Since then, the observation network has evolved. Now, it is composed of 3,800 monitoring points (dug wells, boreholes and piezometers), therefore the national piezometric network now includes a series of measures sometimes with lengthy 50 year series. It allows the observation of 150 water systems (consisting of 166 shallow aquifers and 124 deep aquifers). To characterize this network, a number of indicators have been defined, both for the quality of existing local networks and on the requirements for additional information. The classification of aquifers based on these indicators highlights aspects related to possible network improvements. The overall synthesis of various indicators led to identify the priorities in streamlining the piezometric networks (Horriche & Besbes, 2006).

For hydrogeological systems where tertiary formations predominate, are sometimes rich in clay and gypsum, leading to significant salts concentrations: only 10% of groundwater has a salinity less than 1.5 g/L, 60% between 1.5 and 5 g/L and 30% greater than 5 g/L, this last category being classified as brackish water.

2.3 *Soil water resources*

Water resources in the soil are defined as the proportion of infiltrated rainfall, temporarily stored in the soil, which is available: either for direct evaporation in the case of bare soil, or for crop consumption if the ground is covered. It corresponds to the available water in the soil, a notion used in the hydrological conceptual models. In theory, the total stock of soil water could be used by plants as in the case of very dense coverage such as forest or grass.

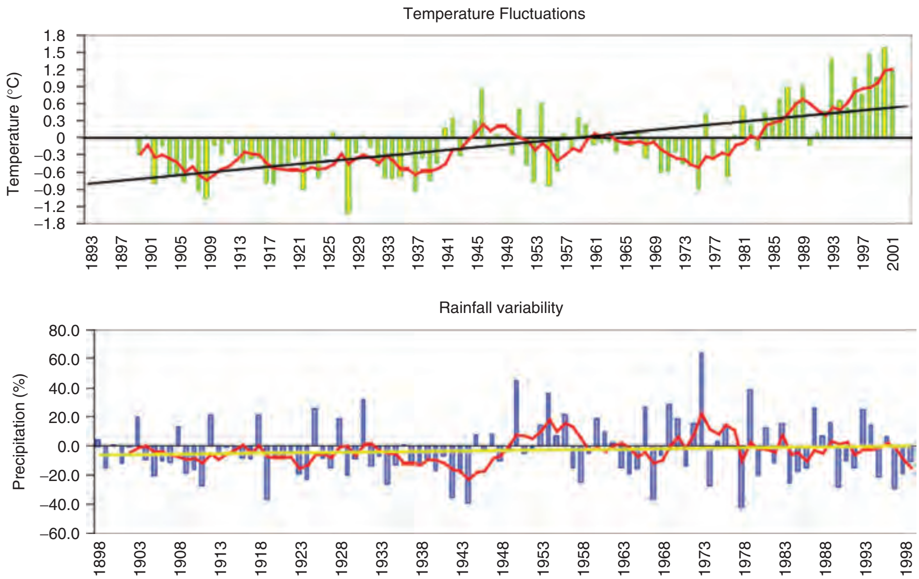

Figure 4. Anomalies in average temperature and precipitation over the past century reconstructed for Tunisia. From MARH–GTZ–Gopa–EXAConsult (2007).

Soil water resources in Tunisia includes arable land (4.5 million ha), rangeland (4.5 million ha) and forests (80,000 ha) on the surface of which the rainfall resource is produced. The evaluation of these resources across the country is a complex undertaking. Although some estimates have been proposed (Ennabli, 1993; Besbes, 1998), which estimate these resources at around 12,000 Mm^3/yr, which include the sum of the equivalent-water related to the rainfed crops, forests and rangelands, and the evaporation on bare soil for an average hydrological year.

2.4 *Climatic variations and impact on water resources*

The analysis of changes in temperature and rainfall averages over Tunisia during the last century (Figure 4) indicates a significant temperature increase estimated at +1.2°C (King *et al*., 2007). This increase is greater than the increase in the global average (+0.7°C) indicated by the 2001 report of the Intergovernmental Panel on Climate Change (IPCC). For precipitation no significant trend is detected. However, it should be observed that the reference period 1961–1990 is characterized by a higher variability (higher standard deviation) in comparison with previous periods (1931–1960 and 1901–1930).

In the context of climate change, the future evolution of rainfall and temperature has been modeled on the global scale but with relatively large uncertainties. The extent and the accuracy nature of future changes remain imprecise (Lahache Gafrej, 2007a). Therefore, caution should be taken in order to implement predictions at the local or regional scales. The medium scenario used by the study confirms these difficulties: if the general increase in temperature is admitted, the evolution of rainfall is sometimes positive and sometimes negative, it varies by regions and season and, globally, the decrease is very low. This will probably not affect the runoff significantly and the inputs to dams. However the decrease in summer rainfall and the increase of temperature and potential evapotranspiration will augment the water deficit of the soil as well as agricultural needs. This could lead to more exploitation of groundwater and a worsening of their salinity. In addition, rising sea levels could exacerbate the salinization of coastal aquifers and might contribute to reduce the potential of groundwater in the long term.

3 MAIN WATER USES

3.1 *Water supply and sanitation*

The only operator in the sector of drinking water for urban, industrial and touristic uses is the National Company for Water Exploitation and Distribution (SONEDE). The rural operators are jointly the SONEDE for rural agglomerated centres of population, and the Administration of Rural Engineering (DGGR) in the rural dispersed areas through water users associations organized into Agricultural Development Groups (GDA): in 2005 there were 1,800 GDA for supplying drinking water to 45% of the rural population (1.6 million inhabitants).

The coverage rate of drinking water in urban areas has evolved from 98% in 1985 to 100% in 1993. These performances were obtained by using large transfers of water from the North, where surface water resources are relatively abundant, to the South, characterized by an arid climate; and through brackish water desalination for the benefit of the tourist areas of the Southeast. The number of urban localities currently supplied with drinking water is about 500 and the individual connection rate is around 99%. Over the past two decades, significant efforts have been made in order to improve access to drinking water in rural areas: the coverage rate has been increased from 30% in 1985 to 92% in 2006. The overall coverage rate for the whole country has evolved from 66% in 1985 to 97% in 2006 (Figure 5).

The volumes distributed by SONEDE networks have attained 405,106 m^3 in 2006. Moreover, part of the water demand is ensured by direct abstractions from groundwater. Applied to the total population, all direct water needs have increased from 30 m^3/yr per capita in 1990 to 40 m^3/yr in 2006.

Concerning urban sanitation, the National Office of Sanitation (ONAS) is the unique operator responsible for wastewater collection and treatment, sludge and solid waste. The rate of wastewater treatment increased from 32% in 1974 (creation of ONAS) to 97% in 2006. The connection rate in urban population reached 87% in 2006. In rural areas, sanitation is still traditional (like septic tanks, a discharge into the natural environment), but the National Office of Sanitation implementing new development programs. All together, many efforts are being made to minimize health risks by promoting behavioral changes in hygiene and by developing health education.

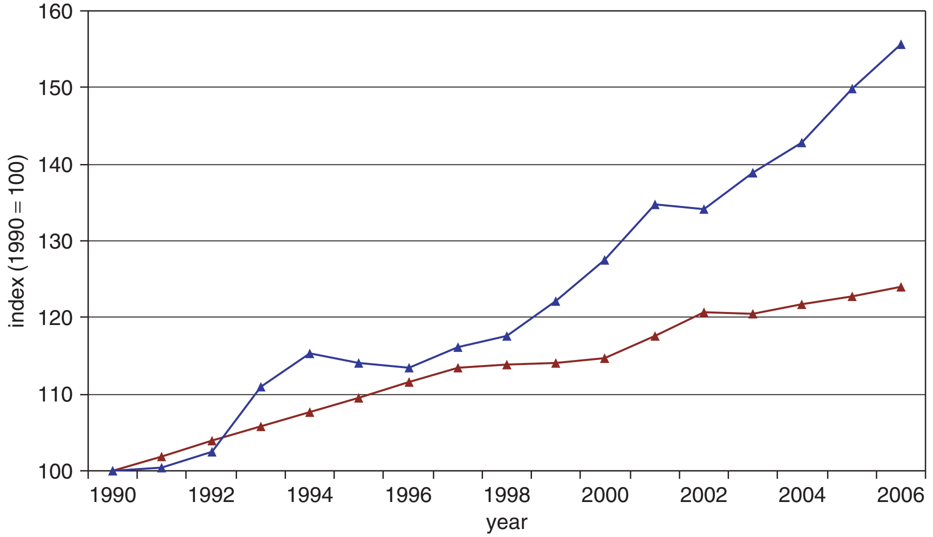

Figure 5. Evolution of the Tunisian population and potable water volumes distributed by public networks.

3.2 *The tourism sector*

Certainly the individual consumption of a tourist (550 L/day per bed occupied, and 900 L/day per bed for 5-star hotels is very high (see Lahache Gafrej, 2007b): this represents five to eight times the daily consumption of the average Tunisian user. However, the sum of consumption for the entire tourism sector reached 25 Mm^3/yr which represents only 1% of all water uses, including agriculture, and 6% of resources allocated to drinking water. This rate is slightly higher in the South where the tourist sector is subjected to strong growth; but this development could be controlled: first by applying new regulations on the audit of large consumers of drinking water (the target is saving 50% in hotels consumption), and secondly by using desalinated seawater.

3.3 *Water and Tunisian agriculture*

The role of agriculture in national economic growth remains important, although proportionally, the agricultural GDP tends to decline slowly. In 2006, agriculture accounted for 11% of GDP, employs 25% of the workforce and involves 475,000 farms with an average area of 11 ha. Industry, mining, and the service sector contribute respectively to 29% and 60% of the GDP. Exports of agricultural products (mainly olive oil and fruits) account for more than 20% of total exports, but agriculture remains dependent on uncertain climatic conditions. The total water abstraction reached 2,640 Mm^3/yr in 2006, including 2,140 Mm^3/yr allocated to irrigation, or 81% (15% for urban uses and 4% for industry). Irrigation water allocation is guaranteed by 75% of groundwater, 24% of surface water, and 1% of the treated wastewater.

Given the water allocated to agriculture, the irrigation potential is estimated at 560,000 ha, comprising 410,000 ha in full or partial control and 150,000 ha of additional irrigation and flood spreading. The total area was about 400,000 ha in 2005, comprising: a) 175,000 ha of informal irrigation by small private exploitations from surface wells and shallow drillings, or from pumping in watercourses; b) 225,000 ha equipped for collective irrigation from deep wells, dams and hillside dams; these equipments are made using public investments. The collective networks are generally modern and waterproof. The efficiency of these networks is estimated at 85%.

A comprehensive program from saving water irrigation began in 1995. Significant financial incentives are offered to promote efficient irrigation equipments. The water subsidies can represent, for small size farms, up to 60% of the facilities costs. Thus, the rate of irrigated area equipment using water saving systems was 80% in 2007 (25% with surface irrigation improvements, 27% with sprinklers, and 28% with drip irrigation). This strategy within ten years allowed the stabilization of the water demand from irrigation, despite the expansion of the irrigated area at the national scale (Figure 6).

On the other hand, irrigation has an important aspect related to *energy*. Indeed, 95% of irrigated areas are equipped with pumping systems and the total pumping capacity has been estimated at

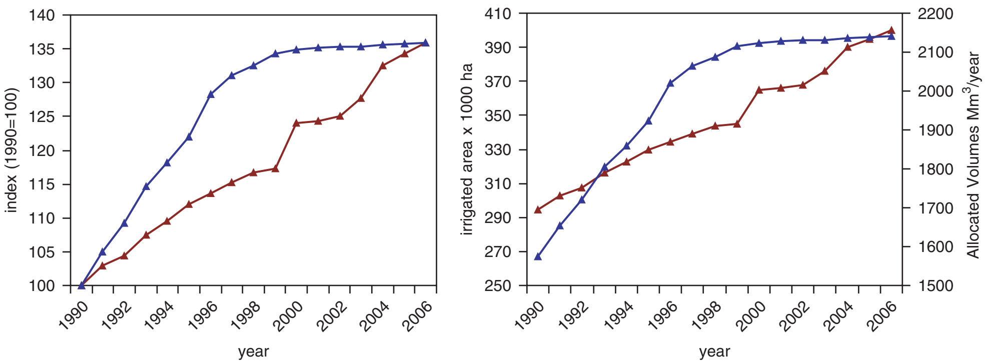

Figure 6. Evolution of irrigated area and water demand for irrigation.

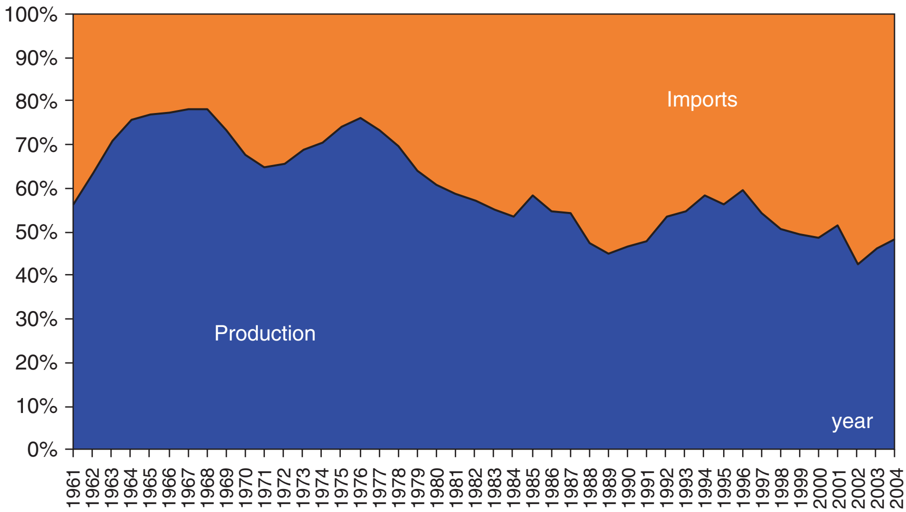

Figure 7. Structure of consumption of wheat in Tunisia.
Source: Besbes *et al.* (2007).

about 160,000 kW in 2005. The irrigation sector represents 27% of agricultural employment. The production of irrigated areas is estimated at 35% of the total agricultural production (in value) and its participation in the export of agriculture products is around 20%.

3.4 *Role of agriculture in food security*

In Tunisia, the concept of food security is understood as an objective to cover a number of commodities involved in food through national production: cereals, oils, meat, milk, potatoes, and sugar. But Tunisia is in deficit for several of these products. On the other hand, the climatic fluctuations induce strong fluctuations in rainfed agriculture production. The agri-food trade balance of Tunisia has been negative during for last two decades, except in wet years like 1999 and 2004. This balance is chronically dependent on cereals imports which represent nearly 45% in value of foodstuffs imports (Figures 7 and 8). However, the overall coverage is evolving positively; the reason for this positive development is that milk and meat are beginning to cover local demand.

3.5 *Foodstuffs trade and Virtual Water exchanges*

The direct water use of different sectors (urban, industry, tourism …) is relatively low compared with agricultural demand. Agricultural demand corresponds to all agricultural water requirements needed to produce food. The concept of water-equivalent (amount of water needed to produce a good) applied to the total food demand can highlight some key aspects of the relationship between agriculture and water resources. It appears that, in an average hydrologic year, nearly the half of the equivalent-water of Tunisian food demand is provided by rainfed crops *Green Water*, and that irrigated agriculture accounts for about one sixth, with almost a third filled by the agri-food trade balance in the form of *Virtual Water*. To supplement food needs, Tunisia imports foodstuffs with an equivalent-water estimated at 5,200 Mm^3/yr, mainly in the form of cereals, and at the same time, the agricultural products export (citrus, dates, vegetables, olive oil, etc.) represent an equivalent-water of 1,500 Mm^3/yr, leaving a balance deficit of 3,700 Mm^3/yr in an average year (Chahed *et al.*, 2007).

As in most arid countries, the contribution of *Virtual Water* to food security is essential, and the volume of food product trade depends closely on the production of rainfed agriculture, whose

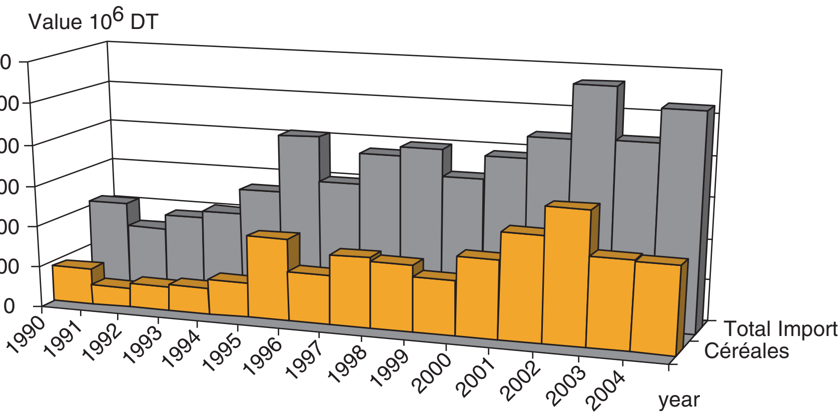

Figure 8. Part of cereals in food imports, in value, 10^6 DT [1 DT = 0.8 US$].
Source: MARH (2005); Besbes *et al*. (2007).

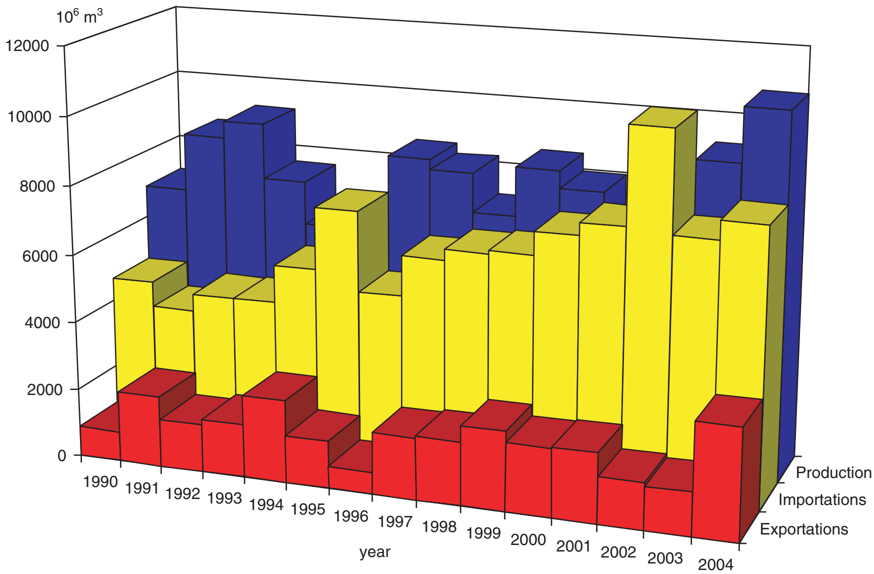

Figure 9. Production, imports, exports of food, expressed in equivalent-water from 1990 to 2004 (Mm^3).
Source: MARH (2005); Besbes *et al*. (2007).

volume is strongly dependent on climatic variations. However, water budgets that result from foodstuffs trade balance are very favorable to Tunisia. The coverage rate of foodstuffs balance, more or less balanced in value, represents less than 30% in equivalent-water (Figure 9).

The current deficit of the equivalent-water related to foodstuffs exchanges might grow in the future because of the change that might occur in food demand, due to eating habits and to the increasing pressure on water resources. Indeed, food needs can change rapidly due to the expected improvements in living standards. The implications of these developments on agriculture and on foodstuffs trade balance are important, especially as changes in trade condition could occur in relation to market developments, to the modification of agricultural policies and to trade liberalization at the international level.

Table 1. *Blue Water* resources potential. After *Eau 21* (Khanfir *et al.*, 1998).

	Potential resources (Mm^3/yr)				Exploitable res. (Mm^3/yr)			
Year	1996	2010	2020	2030	1996	2010	2020	2030
Surface water	2,700	2,700	2,700	2,700	930	1,220	1,173	1,182
Water table aquifer	720	720	720	720	720	720	620	550
Deep aquifer	1,250	1,250	1,250	1,250	997	1,150	1,000	1,000
Total conventional resources	4,670	4,670	4,670	4,670	2,647	3,090	2,793	2,732
Treated sewerage water	250	400	420	440	120	200	290	340
Desalinization	0	0	0	0	0	10	24	49
Total non conventional resources	250	400	420	440	120	210	314	389
Total Resources	4,920	5,070	5,090	5,110	2,767	3,300	3,107	3,121

4 WATER SUPPLY AND DEMAND PROJECTIONS

4.1 *Tunisian water resources*

During the last decades, the Tunisian authorities have implemented a pragmatic policy of systematic development of water resources, in order to sustain the socio-economic development of the country and promote a modern agriculture, so as to increase local food production and promote its export.

Irrigation has been a crucial factor in the increase of agricultural production. Irrigated agriculture is essentially practiced with highly valued products (market vegetable, fruit production). With governmental encouragements for dairy production, irrigation is also practiced in complement for cereals and fodder crops production.

As to the production from rainfed agriculture, it strongly depends on climatic conditions. Nevertheless and despite its variability, rainfed agriculture production plays an essential role in food safety. It plays a double role in the food balance: first, production from rainfed agriculture represents a significant part of the food exports; second, the objective of importing basic food products, particularly cereals which constitute a significant component of the food imports, is to meet the deficit from local production by rainfed agriculture which depends strongly on climatic conditions.

Competition for limited water resources is rapidly increasing and will require more adapted modes of resource management and water allocation. All the studies carried out during the last decades (Hamdane, 1993; Besbes *et al.*, 2002) propose global responses in terms of administration methods and resource management principles, and introduce technical and economic solutions (resource protection, water loss reduction, improvement of water use efficiency, suitable water pricing). With regard to indicators for water resources conservation, results from water sector reforms are already remarkable both in urban systems (Limam, 2007) and in agriculture (Hamdane, 2007): i.e. reduction of water losses and the improvement on the efficiency of water uses.

4.2 *Demand projections*

The official Tunisian study on water resources *Eau 21*, has estimated water resource potential up to 2030 (Table 1, Khanfir *et al.*, 1998). It indicates that the amount of regularly produced conventional *Blue Water* will be almost 2,700 Mm^3 after 2010 (Table 1). The official long-term projections of *Eau 21* predict very rigorous water resource management. The supply-demand adequacy suggested in this study assumes a moderate evolution of direct water demand (domestic, industrial and tourism) and a drastic management of all water uses. According to *Eau 21*, domestic water consumption per capita will remain at 100 L/day in 2030 and water allowance for irrigation will be strongly reduced, by generalizing water saving irrigation systems, from an average allocation of 6,320 m^3/ha/yr in 1996 to 4,335 m^3/ha/yr by 2030. Irrigated surfaces for the same period would go from 335,000 to

Table 2. Initial *Blue Water* demand and projections (in Mm^3/yr). After *Eau 21* (Khanfir *et al*., 1998).

Year	1996	2010	2015	2020	2025	2030
Drinking Water Demand	290	381	410	438	464	491
Industrial Water Demand	104	136	150	164	183	203
Tourism Water Demand	19	31	33	36	39	41
Total Direct Water Demand	413	548	593	638	686	735
Irrigation Water Demand	2,115	2,141	2,115	2,082	2,058	2,035
Total Water Demand	2,528	2,689	2,708	2,720	2,744	2,770

Table 3. Overall water demand of Tunisia (average values for 1990–1997).

Sector	Water Demand (Mm^3/yr)
Irrigation	2,100
Rainfed agriculture [Green Water]	6,000
Deficit of food balance [Imported Virtual Water]	3,700
Urban [Cities, tourism]	400
Industry	100
Forests and Rangelands	5,500
Water Bank [Storage in dams for droughts]	600
Environment [Conservation of humid areas]	100
Total Water Demand	18,500

467,000 ha. The annual water allocation to irrigation would thus be re-examined, from 2,100 Mm^3 in 1996 to 2,030 Mm^3 in 2030 (Table 2).

5 OVERALL WATER BALANCE OF TUNISIA

The future growth of irrigation is mainly limited by the availability of water resources. On the other hand, rainfed agriculture mobilizes a significant part of water resources and contributes to more than 2/3 of food production (cereals, olives, livestock, . . .).

The total available resources resulting from surface and underground runoff *Blue Water*, represents a relatively small part (about one quarter) of the total water resources of the country.

National accounting of water resources for an average year indicates that the overall volume of water resources effectively used is around 18,500 Mm^3/yr (approximately 2,000 m^3/yr per capita) (Table 3). Direct water demand (urban water-use, tourism, industry) is about 50 m^3/yr per capita, and the equivalent-water of food demand reaches 1,300 m^3/yr per capita. As mentioned before, part of this demand is provided by imported foodstuffs products (mainly cereals and vegetable oils) in the form of *Virtual Water*. The deficit of food balance expressed as Equivalent-Water represents 3,700 Mm^3 (about 400 m^3/yr per capita). The rainfed agriculture represents a significant part of water resources in the form of *Green Water* estimated at 6,000 Mm^3. Table 3 shows that rainfed agriculture production (especially cereals, leguminous plants and olives) represents, in terms of Equivalent-Water, a significant contribution (more than half the food demand and about three times the volume of water allocated to irrigated areas). It also appears that food imports represent a considerable contribution, which serves to meet the local production deficit especially that of rainfed agriculture, very variable because of rainfall variability. The agro-alimentary balance deficit represents on average an *Equivalent-Water* contribution of roughly a third of the total food demand expressed as Equivalent-Water.

The overall water balance model of Tunisia highlights some important aspects related to water resource management (Chahed *et al*., 2008). This model assumes that the allowance in *Blue Water* to irrigation (*IW*) must adjust to the available water once the direct needs (*DD*) insured. This water balance is expressed as:

$$IW = EWR - (1 - RI)DD - ENV \quad (1)$$

$$VW = FD - GW - \lambda EWR + \lambda(1 - RI)DD - ENV \quad (2)$$

Equation 1 expresses the irrigation water volume (*IW*) as the difference between exploitable water resources (*EWR*) and the quantities consumed by the direct water demand (*DD*) or allocated to meet environmental demand, the coefficient (*RI*) representing the rate of water recycling. *Equation 2* expresses the water deficit (*VW*, *Virtual Water*) volume as the difference between the equivalent water demand for food (*FD*) and the equivalent-water of agricultural production in both rainfed (*GW*, *Green Water*) and irrigated contributions; the coefficient λ expresses the global irrigation factor which converts irrigation volumes into equivalent water; this factor integrates irrigation efficiency and rainfall contribution. The adjustment of these balances at the national level by comparing them with the data for the two years 1996 and 2004 led to the validation of this formulation. It appears that the rate of coverage of the demand in terms of equivalent-water is mainly controlled by the production of rainfed agriculture and to a lesser extent by the contribution of irrigated area, while direct water demand has a relatively weak effect on the overall balance, even though, as it could be expected, their socio-economic effects at the sectorial level are crucial.

6 AGRICULTURE STRATEGY AND WATER POLICY IN TUNISIA

Tunisia has implemented, relatively rapidly, a pragmatic policy of systematic development of water resources. After engaged in efforts over several decades, Tunisia has managed most of its conventional water resources. This policy also relied on large water transfers and played a crucial role in the development of different sectors of the economy at the national level, including irrigated agriculture. Irrigation has developed significantly and has played a pivotal role in development policies: e.g. the total area equipped for irrigation has increased sevenfold in the past four decades.

On the other hand, rainfed agriculture mobilizes a significant part of water resources and contributes to more than 2/3 of food production (cereals, olives, livestock . . .). Despite the variability of production, rainfed crops also play a key role in food security. Firstly, the production of rainfed agriculture accounts for a significant part of food products exports; and secondly, imports of staple foods including cereals, are mainly intended to cover the deficit in local rainfed agriculture production whose performance is highly dependent on climatic conditions. The two dominant rainfed cropping systems in Tunisia (cereals and olive oil), occupy more than two thirds of land on various soils and in weather conditions more or less favorable to intensification. The average yields of cereals per hectare have been multiplied by three over the past thirty years, but they remain relatively low. Cereal production is still insufficient; it only covers less than the half of the national demand and the difference is made up by imports, whose volume is increasing. The government tries to enhance cereals production promoting irrigation and new farming methods to increase crop productivity (seed selection, fertilizer use, etc.)

Irrigated areas represent 10% of the total cultivated area. Nowadays its future growth is mainly limited by the availability of water resources. The irrigation sector accounts for the largest water demand (80% of exploitable resources). With this potential, irrigated agriculture provides 35% of agricultural production in value and contributes to 25% of agricultural products exports. The direct water demand (urban, tourism, industry) has the advantage of having an absolute priority in the allocation of good quality water resources. This demand remains moderate, but the prospect of development of these different economic sectors will be accompanied by an increase in demand.

On the other hand, the almost complete exploitation of the available resources is accompanied by a number of risks and constraints, particularly with regard to environmental concerns (water quality, variability of resources, environmental restrictions, and overexploitation of underground resources…). The prospect for sustainable management of water resources should lead us to consider all factors and constraints that could affect the resource. In particular, the environmental demand in terms of direct allocation of water resources for lakes, wetlands and groundwater recharge is now considered as a primary factor of sustainable water management. For example, the overall releases from Sejnane, Joumine and Ghezala dams for feeding Ichkeul Lake totaled 750 Mm^3 between 1998 and 2005, corresponding to an inter-annual average volume of about 110 Mm^3.

7 PROSPECTIVE STUDY OF THE OVERALL WATER BALANCE

Since it is predicted that water supply at the national scale is going to stabilize, the pressure on the resource will result in inevitable reallocations that will be operated at the expense of the agricultural sector which, during periods of drought, is the first to suffer from the effects of water scarcity. The reduction of water availability for agriculture is a key issue for water problems in the future. It constitutes the ultimate challenge for current water policy which tries to find the most appropriate ways to meet the growing needs of the different economic sectors without burdening the agricultural sector. In these circumstances this approach leads to pursue the development of the supply to furnish sufficient water increasing the pressure on water resources. This classic hydraulic vision of water resource is incomplete. It does not take into account the important production potential of *Green Water* and does not consider the global food demand. The production of rainfed agriculture reflects an exploitation of non-productive rainfall resources which account for a large part of the overall water balance in the country and thus may effectively participate, as irrigated agriculture, in the national effort to increase agricultural production to meet food challenges.

Significant changes of dietary patterns have occurred in Tunisia in recent decades bringing the water equivalent of food consumption under 700 m^3/yr per capita in the 1960s to a level exceeding 1,400 m^3/yr in 2000 (Figure 10). The fact remains that this level of consumption is relatively low compared with the equivalent-water of developed countries food consumption (1,600 m^3/yr per capita in Europe, 2,200 m^3/yr in California) which corresponds to a diet richer in animal products (proteins).

The prospect of sustained growth in the purchasing power in Tunisia, will result in an increase of the equivalent water for food requirements due to the increase in proteins in the diet. It is indisputable that such changes will have important implications for the water balance and for agriculture. On the other hand, the development of the tourism sector will be coming with additional demand for food products. During 2007, the number of tourists reached almost 7 million with approximately 40 million tourist nights. Even if demand from the tourism sector may represent a relatively small

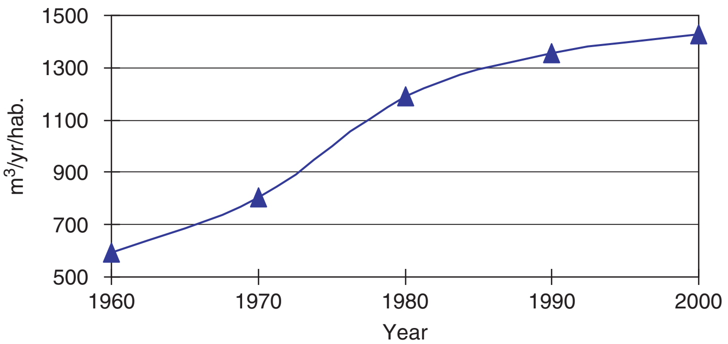

Figure 10. Evolution of per capita water equivalent of the Tunisian food demand during the last 40 years.

part of global food demand, the prospect of growth indicates that its long-term effect cannot be neglected.

Demographic change, economic growth and the aspiration for a better life will result an increased water demand with suitable quality but also quantities increasingly important of foodstuffs. These perspectives point to the need to study patterns of water development and their implications on the national water balance. The simplified formulation of the water balance is therefore useful for simulating the future of water resources in order to prospect different scenarios for water resource management and exploitation. The purpose of these simulations is to assess the impacts of different assumptions on water demand, including the demand for food production. The second objective is to compare different planning and development options for all water resources, including resources used in rainfed agriculture *Green Water*.

The simplified formulation of the water balance is useful for simulating the future of water resources in order to prospect different scenarios for water resource management and exploitation at the national level. Three scenarios are studied: the two first scenarios are called *trend scenarios*, based on the analysis of the actual trends in operations and management of the resource. The third scenario, called *sustainable scenario* is more conceptual in that it broadens the notion of resources to the potential of *Green Water*. This scenario stems from a vision of what we want to see happen in the future in order to ensure sustainable management of all water resources. All of the scenarios suppose the continuation and amplification of the efforts made in recent decades to ensure resource conservation. Taking into account the current effort to increase reuse and recycling of wastewater, the scenarios admit that the rate of water recycling will reach a maximum of 50% by 2025.

7.1 *Trend scenarios*

Trend scenarios are based on a classic vision of water resources planning which considers only *Blue Water* and tries to match the available resource with the water demand. In recent decades, the rainfed cultivated lands have not really evolved and these scenarios will extend these trends considering that the contribution of *Green Water* to the overall water balance will remain constant.

The first simulation (simulation 1) builds on a drastic control of all water uses and on a moderate growth in the direct water demand (potable, industrial, and tourism). The assumptions of this simulation assume that water demand for direct uses is supposed to remain relatively low (60 m^3/yr per capita by 2025 and 70 m^3/yr by 2050) and the equivalent water of food demand is expected to remain largely below the equivalent water of food demand of developed countries (1,600 m^3/yr per capita by 2025 and 1700 m^3/yr by 2050). The second simulation (simulation 2) goes in the direction of more *realism* assuming that water needs will increase reasonably. The assumptions of (simulation 2) consider that the direct water demand will reach 70 m^3/yr per capita by 2025 and 80 m^3/yr by 2050. The simulation also admits that the structure of the diet will be improved, so that the water equivalent of the food demand is expected to reach 1,700 m^3/yr per capita by 2025 and 1,800 m^3/yr by 2050.

7.2 *Sustainable scenario*

The sustainable scenario attempts to build a new water vision, at least in regard to agricultural sector. This scenario corresponds to a desire to benefit from all water and soil resources in order to strengthen the capacity of agricultural production to meet increasing food demand. This simulation implies that efforts will be made to strengthen rainfed agriculture production by developing cultivated areas and by improving crops productivities so that, in an average year, the production of the whole sector will be increased by 25% by 2025 and 40% by 2050. Furthermore, we adopt the same assumptions as (simulation 2) for direct water demand and for the equivalent water demand for food. The results of the simulations for the horizons 2025 and 2050 are summarized in Table 4.

Table 4. Adjustment and prospecting scenarios of the global water balance of Tunisia.

		Trend Scenario Simulation 1		Trend Scenario Simulation 2		Sustainable Scenario	
	2004	2025	2050	2025	2050	2025	2050
Population (10^6 habitants)	9.93	12.15	13	12.15	13	12.15	13
Exploitable Resource (EWR) (Mm^3/yr)	2,500	2,700	2,700	2,700	2,700	2,700	2,700
Food demand, Eq. water (m^3/yr per capita)	1,450	1,600	1,700	1,700	1,800	1,700	1,800
Total food demand (FD), Eq. water (Mm^3/yr)	14,399	19,440	22,100	20,655	23,400	20,655	23,400
Direct water demand (m^3/yr per capita)	55	60	70	70	80	70	80
Total direct water demand (DD) (Mm^3/yr)	546	729	910	851	1,040	851	1,040
Reuse rate (RI)	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Total irrigation allocation (IW) (Mm^3/yr)	2,008	2,336	2,245	2,275	2,180	2,275	2,180
Rainfed agriculture (GW), Eq. water (Mm^3/yr)	8,000	8,000	8,000	8,000	8,000	10,000	11,200
Conversion factor, λ	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Deficit of food balance (VW) Eq. water (Mm^3/yr)	4,591	9,338	12,080	10,608	13,438	8,608	10,238
Total water demand	14,945	20,169	23,010	21,506	24,440	21,506	24,440
Rate of dependency	31%	46%	52%	49%	55%	40%	42%

8 RESULTS, DISCUSSIONS AND FURTHER EXPECTED DEVELOPMENTS

Tunisia is an arid area where water resources are almost entirely mobilized. The country is therefore obliged to apply new concepts and paradigms to optimize the use of different types of water resources, and to change the behavior of some parts of the population (Chahed *et al*., 2007; 2008; Besbes *et al*., 2007). Global water resource assessment indicates that the improvement of food safety will depend on the capacity of the country to manage and optimize the use of all kinds of water resources. Expressed in term of Equivalent-Water, rainfed agriculture *Green Water* and the contribution of the agro-alimentary trade balance *Virtual Water* appear to be very important. On the other hand, food dependence is likely to develop with the change in diets.

Considering the current state of water resource management and exploitation in Tunisia, the improvement of the agro-alimentary balance requires a better understanding of the important relation between water and agricultural production in order to optimize the use of all water resources. This corresponds to a global vision of water resource which goes beyond the traditional concept of withdrawal water to cover all kinds of water resources and all water uses including those for food demand.

The simulations of the trend scenarios indicate that the increase in population, relatively well controlled, will induce an increase in foodstuffs imports (expressed in water equivalent), even if the consumption level is maintained relatively low (simulation 1). In this best case, the volume of *Virtual Water* will be multiplied by a factor 2 by 2025. Irrigated agriculture is unable by itself to meet changing demand and the coverage rate of the food balance expressed in Equivalent-Water decreases significantly.

The second trend scenario (simulation 2) based on a realistic increase in water uses supposes that the direct water demand will increase significantly. It follows that the residual resource to be allocated to the agricultural sector will be reduced. This reduction will have little effect on the agricultural water allocation because of the prospects for increased reuse and recycling of water resources allocated to urban, industrial and tourist sectors.

The simulation of the sustainable scenario shows the essential role of rainfed agriculture in the overall water balance. The increase in rainfed agriculture production will bring the averaged Equivalent-Water of rainfed agriculture to 10,000 Mm^3 by 2025 and to 11,200 Mm^3 by 2050 against 8,000 Mm^3 in the initial period. This would maintain the coverage rate of foodstuffs production expressed in water equivalent to a much more favorable level facing the increase of all water demands, including the demand for food production.

The integral vision of water resource leads to a global water balance which confronts the real possibilities of water resources to the whole water demand. In such conditions, it becomes possible to value and optimize all kinds of water resources (improvement of water use efficiency, inclusion of rainfed agriculture, development of alternative water resources, optimization of *Virtual Water* fluxes, etc.). The question of water resources scarcity is obviously related to the safety of direct water demand supply (urban, industrial, tourism), but and above all to food security.

In a context of water resource limitation, this large perception of water resources is most favorable to the development of new ideas and strategies aiming at reducing the deficit of the agro-alimentary trade balance and improving food security. Some progress has to be sought in: (a) improvement of water use efficiency, in particular for irrigation; (b) inclusion of all water resources in particular that involved in rainfed agriculture production; (c) intensive use of water and soil conservation techniques; (d) improvement of plant varieties with regard to their adaptation to aridity; (e) development of suitable policies for management and control of food demand evolution; (f) optimization of agro-alimentary exchanges by taking into account their effects on the water resource balance. This last point should result in agro-alimentary trade that promotes import of food (and more generally products and services) requiring a lot of water (water-intensive products) and export of products requiring less water (water-extensive products).

The formulation of the overall balance of water resources is relevant in that it highlights the order of magnitude of the different elements of the water balance. However, the overall balance established at the national level hides huge disparities affecting surface and groundwater resource *Blue Water* as well as water resources mobilized directly by the crops *Green Water*. On the other hand, the regions where water resources are available do not always correspond to regions of high water consumption. Thus water policy in Tunisia has drawn heavily on the massive transfer of resources from areas where the resource is abundant toward zones with high water consumption in the coastal regions. These transfers, which involve water with very good quality, represent 25% of the total exploitable resources.

These considerations lead to regionalize the water balance in order to clarify these differences and to measure their impacts on the overall water balance. Built on the same assumptions as for the national overall water balance, the water balance applied to the region (i) supposes also that water resources are divided according to a classification of quality (quality criterion noted k). This balance is written in the form:

$$IW_{ki} = \sum_k \left[EWR_{ki} + \sum_j [I_{kij}] - (1 - RI_{ki})DD_{ki} - ENV_{ki} \right] \tag{3}$$

$$VW = FD - \sum_i \left[GW_i + \sum_k \left[\lambda_{ki} \left[EWR_{ki} + \sum_j [I_{kij}] - DD_{ki} - ENV_{ki} \right] + \lambda_{REU_{ki}} (1 - TR_{ki}) ED_{ki} \right] \right] \tag{4}$$

Where I_{ij} is the volume transferred from region (j) to region (i) that verifies $I_{ij} = -I_{ji}$ and $I_{ii} = 0$ so that $\sum_i \sum_j I_{ij} = 0$

The parameters of *Equations 3 and 4* are the same as those expressed in the national water balance (*Equations 1 and 2*). They are associated here to the region (i) and to the class of water quality (k). λ_{REU} denotes the irrigation factor related to reused treated water.

This regionalization leads to more detailed informations; not only on the availability of the resources but also on their quality. This regionalization will also pose the issue *Green Water* assessment at the regional scale; knowing that there can also be *Green Water* transfers between the resources involved in the maintenance of rangelands and in logging and those employed in agricultural production. As part of ongoing research, we are developing the evaluation, at regional scales, of the *Green Water* potential on the basis of statistical data of the regional agricultural production.

REFERENCES

Allan, J.A. (1998). Virtual water: a strategic resource. Global solutions to regional deficits. *Ground Water*, 36(4): 545–546.

Besbes, M. (1998). *Gestion durable des ressources en eau: éléments pour l'élaboration d'une stratégie*. Institut Tunisien d'Etudes Stratégiques, Tunis.

Besbes, M.; Chahed, J.; Bargaoui, Z.; Mattoussi, M.S. & Mhiri, A. (2002). *L'avenir de l'eau, un nouveau challenge pour la Tunisie*. Int. Rep. Tunisian Institute for Strategic Studies (ITES), Tunis.

Besbes, M.; Chahed, J. & Hamdane, A. (2007). Bilan intégral des ressources en eau, sécurité hydrique et sécurité alimentaire. Communication at Académie d'Agriculture. Paris, session of April, 4th 2007 (l'Avenir des Eaux Continentales).

Besbes, M.; Chahed, J.; Hamdane, A. & De Marsily, G. (2010). Changing Water Resources and Food Supply in Arid Zones: Tunisia. In: G. Schneider-Madanes & M.F Courel (eds.), *Water and Sustainability in Arid Regions*. Springer.

Chahed, J.; Besbes, M. & Hamdane, A. (2007). Stress hydrique et sécurité alimentaire, une vision intégrale des ressources en eau. *La Houille Blanche*, no. 3.

Chahed J.; Hamdane, A. & Besbes, M. (2008). A comprehensive water balance of Tunisia: blue water, green water and virtual water. *Water International*, 33(4): 415–424.

Chapagain, A.K. & Hoekstra, A.Y. (2004). Water footprints of nations, Value of Water Research Report Series, 16. UNESCO-IHE, Delft, the Netherlands.

De Marsily, G. (2006). Les eaux continentales. Rapport sur la Science et la Technologie, 25. Académie des Sciences, Institut de France. Paris: EDP Sciences.

Ennabli, N. (1993). Les aménagements hydrauliques et hydro-agricoles en Tunisie. Imprimerie Officielle, Tunis.

Frigui, H.L. (2005). Rapport National sur la mise en valeur des ressources en eau en Tunisie. Nations Unies, Commission Economique pour l'Afrique ; CEA-AN/PUB/EAU/TN/7.

Gleick, P.H. (1996). Basic water requirements for human activities: Meeting basic needs. *Water International*, 21(2): 83–92.

Hamdane, A. (1993). La gestion de l'eau en Tunisie. Rapport de synthèse. Tunis. Ministère de l'Agriculture, Tunisie.

Hamdane, A. (2007). Tunisia National report on monitoring progress and promotion of water demand management policies. Water demand management in the Mediterranean, progress and policies. Blue Plan, Zaragoza, Spain.

Hamza, M. (2006). Ressources en eau de la Tunisie. DGRE, January. Tunis.

Hoekstra, A.Y. (2003). Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade. Delft, The Netherlands, December 12–13, 2002. Value of Water Research Report Series, 12. IHE, Delft, the Netherlands.

Hoekstra, A.Y. & Chapagain, A.K. (2007). Water footprints of nations: water use by people as a function of their consumption pattern. *Water Resources Management*, 21(1): 35–48.

Hoekstra, A.Y. & Hung, P.Q. (2002). Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade. Value of Water Research Report Series, 11. UNESCO-IHE, Delft, the Netherlands.

Horriche, F. & Besbes, M. (2006). Analyse du Réseau Piézométrique National Tunisien. *Revue des Sciences de l'Eau*, 19(4): 347–363.

INS (Institut National des Statistiques) (2005). Prévisions Démographiques Nationales, Tunis, August.

Kallel, R. (1994). Caractéristiques morphologiques et hydrologiques du réseau hydrographique Tunisien. DGRE, Tunisia.
Khanfir, R.; El Echi, M.L.; Louati, M.; Marzouk, A.; Frigui, H.L. & Alouini, A. (1998). EAU21: Stratégie du secteur de l'eau en Tunisie à long terme 2030.
King, L.; Nasr, Z.; Almohamad, H. & Maag, C.C. (2007). Le Climat. In: MARH–GTZ–Gopa–EXAConsult, *Stratégie nationale d'adaptation de l'agriculture tunisienne et des écosystèmes aux changements climatiques*. Chapter 7.2. Tunis.
Lahache Gafrej, R. (2007a). Les Ressources en eau. In: MARH–GTZ–Gopa–EXAConsult, *Stratégie nationale d'adaptation de l'agriculture tunisienne et des écosystèmes aux changements climatiques*. Chapter 7.3. Tunis.
Lahache Gafrej, R. (2007b). Comment réduire la consommation d'Eau dans le secteur touristique en Tunisie, approche et stratégie. Water demand management in the Mediterranean, progress and policies. Blue Plan, Zaragoza, Spain.
Limam, A. (2007). La tarification progressive: un outil de gestion de la demande; cas de l'eau potable en Tunisie. Water demand management in the Mediterranean, progress and policies. Blue Plan, Zaragoza, Spain.
Liu, J. (2007). Modelling global water and food relations; development and application of a GIS-based EPIC model. Dissertation ETH No. 17069. Swiss Federal Institute of Technology, Zürich, Switzerland.
MARH (2005). *Annuaire des statistiques agricoles*. Ministère de l'Agriculture et des Ressources Hydrauliques, Tunisia.
MARH–GTZ–Gopa–EXAConsult (2007). Stratégie nationale d'adaptation de l'agriculture tunisienne et des écosystèmes aux changements climatiques, Tunis.
Oki, T.; Sato, M.; Kawamura, A.; Miyake, M.; Kanae, S. & Musiake, K. (2003). Virtual water trade to Japan and in the world. In: Hoekstra A.Y. (ed.), *Virtual water trade*. Proceedings of the International Expert Meeting on Virtual Water Trade. Delft, the Netherlands, 12–13 December 2002. Value of Water Research Report Series, 12. IHE, Delft, the Netherlands.
Renault, D. & Wallender, W.W. (2000). Nutritional Water Productivity and Diets: From crop per drop towards nutrition per drop. *Agricultural Water Management*, 45: 275–296.
UNESCO (2009). *The UN Water Development Report 3. Cases studies volume: Tunisia*: 12–15.
Warner, D.B. (1995). Water needs and demands: Trends and opportunities from a domestic water supply, sanitation and health perspective. *Workshop on Scenarios and Water Futures*, Stockholm Environment Institute, Boston, Massachusetts, USA, 28–30 September 1995.