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Estimation and management of the future evolution of groundwater water demand in the Taoura region, North-East Algeria

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Abstract

Evaluating the capacity to meet the need of water is crucial in order to fulfil expectations of managers, particularly in the Mediterranean area. The region is risk in terms of resources available as well as a steadily increasing in demand for water. The frontier drain of the city of Souk Ahras is located at the extreme Northeast of Algeria, on the Algerian-Tunisian borders, the study region includes eight city, which are Taoura, Drea, Zaârouria, Merahna, Ouillen, SidiFredj, Heddada and Khedara, these are relatively poor in surface water, but groundwater has always been the main water resource. The region's population is around 93,000 inhabitants, 45% of them living in rural areas. Annual average precipitation is approximately 470 mm$\cdot$y^{-1}, but it is distributed unequally in space and time. The average supply water varies from one zone to another and the coverage of demand by groundwater in the region remains low and does not meet all needs. Faced with the regions socioeconomic growth and development, this situation is expected to worsen in the future.

In this context, the WEAP (**W**ater **E**valuation **A**nd **P**lanning system) model was applied to simulate the water balance and assess strategies for the sustainable management of water resources and makes it possible to explore different scenarios, in order to choose the desired scenario to ensure the sustainable development of the sub-basin of the border until 2050. The availability of drinking water permanently in rural areas is a factor in the stability of a population and a means of combating the rural migration and the congestion of urban centres.

Key words: *Algeria, annual average precipitation, groundwater, socioeconomic development, sustainable resource management, Taoura, WEAP model*

INTRODUCTION

Water security is one of the most tangible and dynamic social, political and economic challenges facing many countries. Algeria is recognized as having an arid to semi-arid climate with irregular and generally insufficient rainfall. With the irregular distribution of surface and groundwater resources across the country, it is now certain that water scarcity will be a recurring and structural problem by 2050 and not the consequence of an exceptional weather year. Freshwater resources are limited, especially groundwater, the latter constituting one of the most important sources of drinking water supply in the communes and Mechtas of the city of Souk Ahras, with a demand for water which is ever increasing [ROUAIBIA, DJABRI 2017].

Several regions which are supplied by groundwater alone suffer from problems with the supply of drinking water. For example, the border drain of the city of Souk Ahras, which represents eight communes and is fed by the underground aquifer of Taoura, located in the middle of the large watershed of Medjerda-Mellegue [BOUROUBI- OUADFEL, DEJBBAR 2016; BOUROUGA 2015]. This basin is relatively rich in underground and surface water resources [DJABA 2010, KADI 1997]. This aquifer is considered

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important from the hydrological and hydrogeological point of view for the following reasons (i) more than 70% of the water resources are obtained in karst and cracked aquifers at the centre of Taoura [BOUROUBI-OUADFEL *et al* 2012; DÖRFLIGER *et al*. 2010] (ii) about 42 wells have been drilled to provide drinking water to the populations of this region [DAHDOUH 2012; DAHDOUH 1987; GOUASSMI 2015], and (iii) the quality of water is good and does not require specific and expensive treatments [ROUAIBIA *et al*. 2020]. Groundwater recharge is estimated at 30% of the annual average precipitation, the quantity of water produced in 2018 was estimated at 37,000 m^3 per day in the Taoura aquifer, 6000 m^3 per day at the Bir Louhichi aquifer (Heddada). The daily average endowment in urban areas varies from 90 to 120 dm^3 per person per day, unlike in rural areas and various agglomerations where the daily average endowment is around 70 dm^3 per person per day [ADE 2018; DWR 2018]. The coverage of the groundwater demand in the region remains low and does not meet all needs [BOUROUGA *et al*. 2019]. The decrease in rainfall after the droughts of 2014–2018 caused a drop in the levels of the Taoura aquifer by around 0.5 m to 1.0 m per year. The problem of the drinking water supply deficit is not related to water resources but in the management of these resources. Although this situation is continuing to worsen and questions the region's future, no serious study has yet been carried out to assess water management taking into account current and future probable conditions. Water resources are starting to become scarce for multiple reasons such as the socioeconomic development of the region (the growth of cities, industries as well as the modernization of agriculture) [BLINDA, THIVET 2009], the mismanagement of existing resources, waste due to the unrestrained use of water, the variation and change of climate and its impact on resources [KHOUALDIA, HAMMAR 2017].

The question that arises is this: how should water be managed sustainably now and for future generations to come? For this reason, the WEAP (Water Evaluation and Planning System) model was chosen as the approach method. In this context, the WEAP model is a forecasting tool which simulates all water resources and is favourable for establishing a water resources management plans. We are trying to plan the integration of water resources, and we can assess probable and feasible strategic scenarios to meet future water demands and to obtain better integrated and sustainable management in our region.

MATERIAL AND METHODS

STUDY AREA

The study area is located in the territory of the Souk Ahras city between the meridians of 7°37' to 8° 25' East and the parallels 36°05' to 36°27' North, the study area takes the form of a vast syncline, bordered to the north and south by anticlines [GUASMI 2005]. The study region includes the areas of the municipalities of Taoura, Drea, Zaârouria, Merahna, Ouillen, Sidi Fredj, Heddada, and finally Khedara (Fig. 1), it occupies an area of approximately 1,589 km², with a population of more than 96,000 inhabitants, almost 90% of this population are cultivators, the population growth rate is estimated, according to the last two censuses, as 1.21% [DPL 2008; 2009].

The Taoura region is a collapsing basin surrounded by karstified massifs, the majority of which are Lower Maestrichtian limestone formations trending NE–SW, generally made up of limestone, sandstone, marl, gravel and alluvium. The tectonic overview highlights soft tectonics (folds in the form of anticlines and synclines) and brittle tectonics (faults) to which is added a very important Triassic tectonics

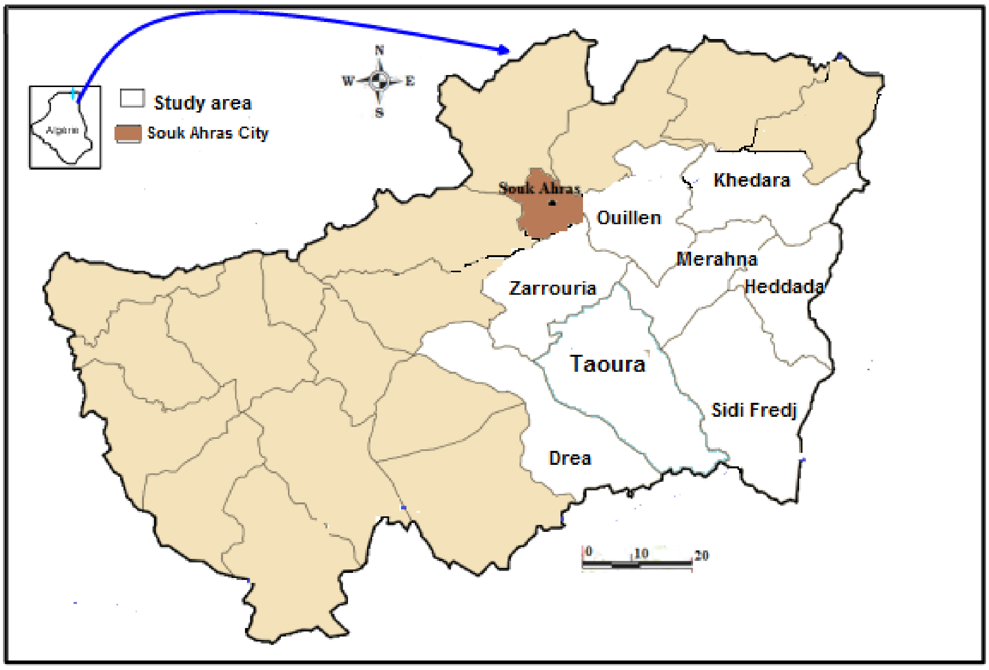

Fig. 1. Geographic situation of the study area; source: own elaboration

[DAVID 1956]. The latter is fed from precipitation water or by water coming from the different areas draining the cross-border Medjerda-Mellègue watershed. The study region is subject to a semi-arid climate, characterized by two seasons, one wet and cold (November–May) and the other dry and hot (June–October). With an average annual precipitation of around 704 mm·y^{-1}, the average annual temperature is around 16.01°C, with a high rate of evaporation estimated at 387.1 mm·y^{-1}, a layer of runoff about of 71.89 mm and a volume of infiltrated water of the order of 23.90 mln m^3·y^{-1}.

Groundwater flow generally takes place from south to north. The estimate of the water capacity of the fissured limestones of the Taoura syncline is 44 Mm^3. The transmissivity values varying between 10^{-2} m^2·s^{-1} and 5.6·10^{-3} m^2·s^{-1}. The storage coefficient is of the order of 9·10^{-3} [BOUCHLAGHEM, HMOUDI 2009], which confirms the presence of cracking and karstification of the water table. The average permeability is of the order of 10^{-5} m·s^{-1}. The hydraulic gradient is highly variable with an average of around 2–5 m·km^{-1}. The altitude of the substratum varies between 100 and 700 m forming the outline of the syncline.

In the study area, the vegetation is closely linked to rainfall. This zone is essentially composed of a free surface water table characterizing the Mio-Plio-Quaternary filling categorised by flows ranging from 0.5–8.0 dm^3·s^{-1}, and a deep captive water table which corresponds to the cracked and karstified limestone of the Cretaceous [BORRELL-ESTUPINA *et al*. 2012], with a flow which varies between 10 dm^3·s^{-1} up to 130 dm^3·s^{-1}. Hydrodynamic exchanges could be done thanks to the fault system that affects the area [CHABBI *et al.* 2012].

WEAP MODEL

In this context we choose the WEAP model (Water Evaluation and Planning system). The WEAP model developed by the Stockholm Environment Institute (SEI) is distinguished by its integrated approach to simulating water systems and by its policy orientation [SIEBER 2006]. The WEAP model is widely used to analyse water resource allocation by establishing the relationship between regional water supply and demand, using the basic principle of water supply and demand balance [HAMLAT 2012; SIEBER, PURKEY 2006]. The model uses standard linear programming to solve water resource allocation problems at each time-step of analysis for integrated water resource planning. The WEAP model can also build and analyse different future scenarios using alternative assumptions about the impacts of water demand and supply policies [YATES *et al*. 2005]. The model will simulate water system functioning in the study zone of Taoura in period 1998–2050. It is a planning tool which was created in 1988, based on a calculation program, which requires several stages and different scenarios. These have been defined to determine the measures that will make it possible to reach a water balance situation by 2050.

TAOURA CENTER MODEL MAPPING

Figures 1 and 2 defines the limits of our study region, the WEAP world map of which is used. This map is created in ArcVeiw file (Fig. 3). The latter is GIS software developed by ESRI and widely used worldwide.

In our study, the starting year of the horizon is 1998. This year is considered as the base year. All the necessary data will be entered from this year. For the future horizon, the year 2050 is selected as the end date. The objective of this reflection proposes an exercise of construction of various scenarios taking into account the socioeconomic, technological, climatic evolution and even the evolution of the ratio supply/demand of the proposed water. In our project we used four key assumptions which are:

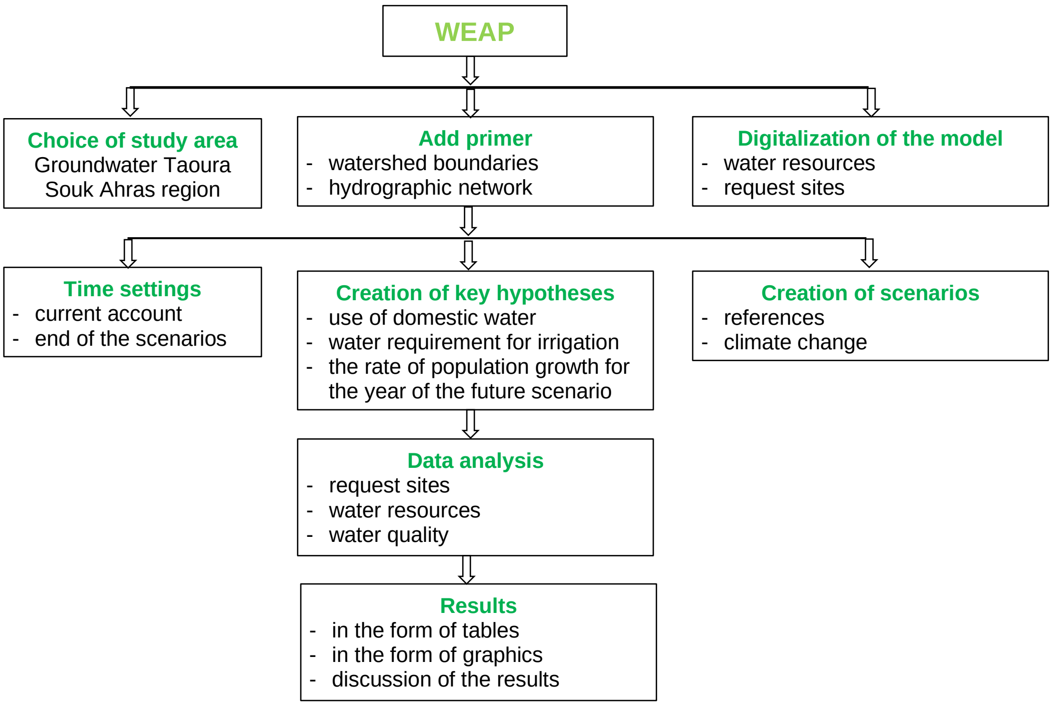

Fig. 2. Flowchart of the operation of the software; source: own elaboration

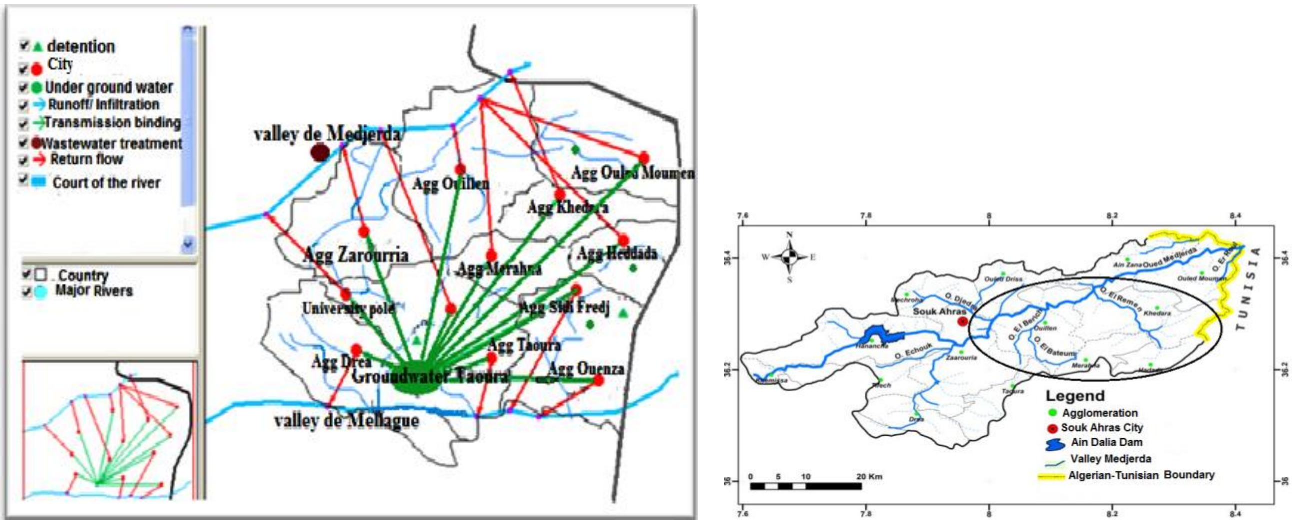

Fig. 3. Modulation of the Taoura Centre; source: own elaboration

- **Assumption 1 Increase in the Average Daily Allowance (ADMJ)**

For the town of Souk Ahras, the daily average endowment in urban areas varies from 110 to 120 dm^3 per person per day, unlike in rural areas, such as Taoura, the daily average endowment is around 90 dm^3 [DWR 2015]. Local officials in the financial sector have more than 20 thous. USD since 2006 in the drinking water supply sector. Spending has included the realization, rehabilitation, strengthening and improvement of drinking water supply networks across the city with an aim of improving the daily endowment of residents [DPL 2009]. In this scenario, we start with an average current endowment of 90 dm^{3}per person per day (32.85 m^3·y^{-1}·inhabitant^{-1}) from then the year 1999 until the year 2015. From this year, the endowment will be close to national standards, in which we adopt an average endowment of around 150 dm^3 per person per day.

- **Assumption 2 Decreasing the Loss Rate (DTP)**

As part of a diagnostic and rehabilitation study of the drinking water supply systems in the city of Souk Ahras, the French design office estimated losses in the network at more than 50% [BCEOM 2008]. We suppose that the rate of loss will decrease in the period 2010–2050 from 50% to 20%.

- **Assumption 3 Use of Recovered Rainwater (UENC)**

In the city of Souk Ahras, the use of recovered rainwater meets more than 30% of domestic needs [GUEBAILI *et al*. 2011]. Based on these results, the proposed the scenario of using recovered rainwater to remedy the problem of insufficient water was put forward. This scenario was applicable in 2010 with a recovery rate of 30% [SANTIKAYASA 2014].

- **Assumption 4 Increase in Maximum Groundwater Withdrawal (APM)**

There are two types of groundwater mobilization works in the study area: boreholes and wells. The drinking water supply is mainly consumed by boreholes; mobilizing an amount of water estimated at 5.36 hm^3·y^{-1}, however for the wells, the figures are not listed because most of them are illicit. However, in the last WNP report an estimate of the volumes withdrawn by aquifer system according to the watersheds were given as follows.

Algerian water company (DA) produces more than 16 Mm^3 of water annually. 20% of this quantity was exploited from the Taoura aquifer with a maximum withdrawal of 3500 m^3·day^{-1} [AWC 2008; 2018] through 42 boreholes and a significant number of sources and individual wells. Considering the significant increase in water demand in the Taoura Centre compared to the quantity of water exploited from the borehole, and noting the difference between the theoretical flow and the exploited flow [DWR 2008; 2018]. This scenario is based on the increase in maximum withdrawals by all possible means to reach the maximum exploitation of these resources, whether by increasing the operating throughput or by achieving drilling levels and the maintenance of drilling stopped.

Volume of water demand = number of inhabitants x volume of annual water per inhabitant

RESULTS AND DISCUSSION

FUTURE EVOLUTION OF THE AVAILABLE RESOURCE

Evaluation of the future supply/demand ratio

Drinking water needs are generally assessed according to two essential criteria, namely:

- the evolution of the population according to the rate of demographic growth,
- the variation in the daily average endowment per inhabitant of each region.

The demand for domestic water in the Taoura Centre, (Fig. 4), shows more monthly variations from one site to another. This variation is generally linked to the change in the annual activity level of each demand site. Indeed, the demand for water is highest at the Taoura City; when the population reaches 24,000 the demand should be 0.79 Mm^3 and by the year 2050 the demand for water will reach 1.06 Mm^3 with a population of 32,500.

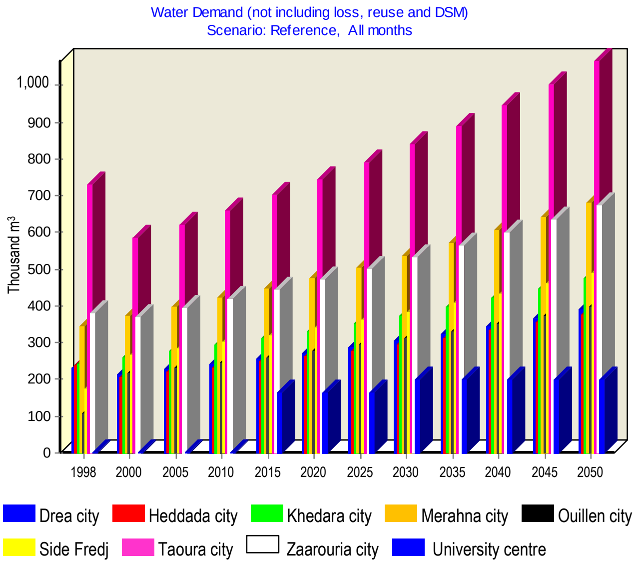

Fig. 4. Water demand (baseline scenario); source: own study

Additionally, it should be noted that in the modelled scenario the water demand in cities is set to rise, whilst in the university centre it is set to remain more or less constant. Two levels appeared, the first is spread over the first fortnight of activity, the second is spread over the rest of the horizon. The demand for water in the first stage is around 0.16 Mm^3. The second level represents a water demand of 0.2 Mm^3.

Evolution of the quantity of water distributed

Growing demand for water has a major impact on water distribution. In the reference scenario, the aquifer can only give a volume of water of the order of 0.55 Mm^3 for the year 2050 as shown in Figure 5. Faced with these requests, the volume of water distributed by the Taoura aquifer is around 0.13 $Mm^3 \cdot y^{-1}$ 2030. This volume continues to decrease until it reaches 0.11 $Mm^3 \cdot y^{-1}$. In 2040 and 0.1 $Mm^3 \cdot y^{-1}$ in 2050.

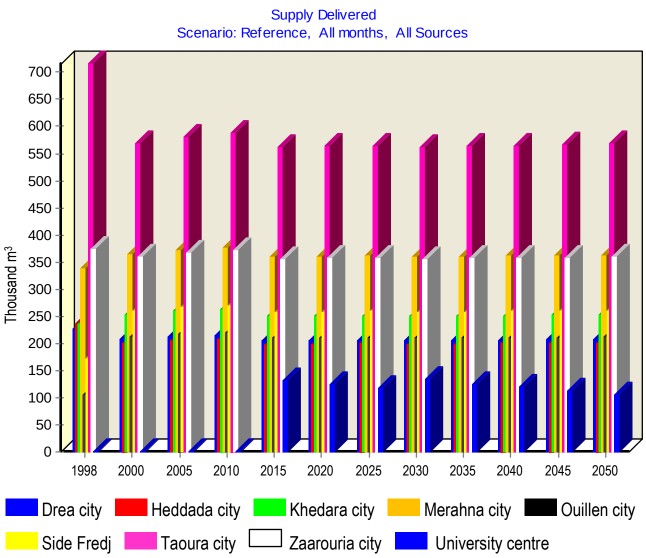

Fig. 5. The volume of water distributed (reference scenario); source: own study

The volume of water distributed is limited either by natural recharge of the aquifer or by the maximum withdrawal capacity [BOUKHARI *et al*. 2012].

The evolution of the amount of unsatisfied water

The Equation (1), is frequently used by the WEAP model to define the name water demand satisfied.

$$V_u = V_r - V_d \tag{1}$$

where: V_u = volume of unsatisfied water, V_r = volume of water requested, V_d = volume of water distributed.

If we compare the balance of supply and demand, the study area is in deficit. The quantity of water satisfied illustrated in Figure 6, for 2025 is around 0.24 Mm^3. This quantity increases to 0.50 Mm^3 in the year 2050. The satisfaction rate in the year 1998 is 98%. However, the results show that the latter marks a significant decrease along the horizon. The satisfaction rate in 2010 will fall to 93% and further falling to 72% by 2025 and becoming as low as 50% by the year 2050. This lack of water is increasing more and more with an increase in demand. In comparison the other demand sites have, more or less, the same evolution of the rate of water satisfaction as the Taoura site, each following their annual activity level. Table 1 summarizes the volume of water distribution for all demand sites. Subsequently, the consequences of the current water management is alarming. In fact, around 50% of the population of the Taoura demand site will have no water by the year 2050.

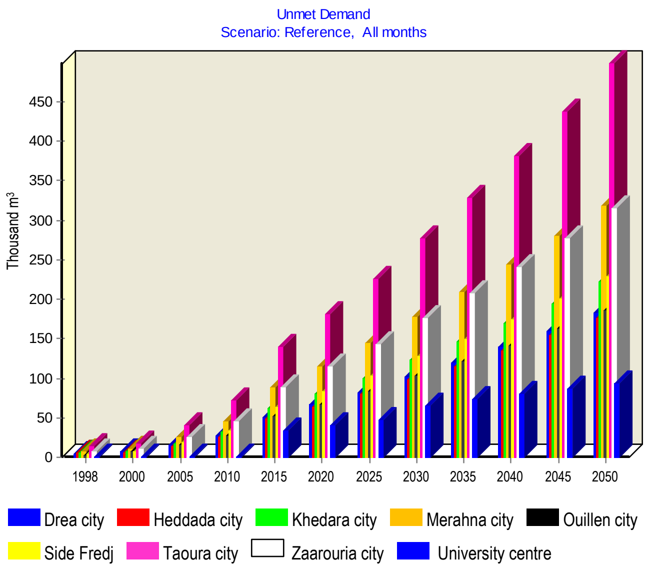

Fig. 6. The amount of unsatisfied water (baseline scenario); source: own study

Analysis of the proposed scenarios

Different scenarios have been defined to determine the measures that will make it possible to reach a water equilibrium situation by 2050. These scenarios are based on current water resource development programmes, on water resources and demand, and generally used technical variables.

Table 1. The volume of water distributed for domestic use for all demand sites (reference scenario)

Year	Volume (Mm^3)											
	1998	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Taoura City	0.72	0.57	0.58	0.59	0.53	0.54	0.54	0.54	0.54	0.55	0.55	0.55
Merahna City	0.34	0.36	0.37	0.38	0.34	0.34	0.34	0.35	0.35	0.35	0.35	0.35
Zaârouria City	0.37	0.36	0.37	0.37	0.34	0.34	0.34	0.34	0.34	0.35	0.35	0.35
Sidi Fredj City	0.17	0.26	0.27	0.27	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Khedara City	0.24	0.25	0.26	0.26	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Ouillen City	0.10	0.21	0.22	0.22	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Drea City	0.23	0.21	0.21	0.21	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Heddada City	0.23	0.20	0.20	0.21	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
University Centre	0	0	0	0	0.25	0.24	0.22	0.21	0.20	0.19	0.18	0.17
Sum	**2.40**	**2.42**	**2.47**	**2.50**	**2.52**	**2.52**	**2.52**	**2.52**	**2.52**	**2.52**	**2.52**	**2.52**

Source: own study.

The year 1998 was chosen to serve as the base year for the model and the entire information system (demand and distribution data) is introduced in the current state. The water crisis we are experiencing today is the result of mismanagement in the past. Above all, given demographic growth, probable climate change, economic and social changes, the demand for water will inevitably increase and a risk of lack of water can no longer be ruled out.

- **Scenario of the increase in the daily average endowment (ADMJ)**

For this scenario, given the assumption of the socioeconomic development of Taoura, the annual consumption per capita is around 55 $m^3 \cdot y^{-1}$

The scenario of increasing the daily average endowment by 40% is a more likely scenario to meet national standards of human needs. Knowing that our daily endowment per capita remains low by international standards Indeed, the importance is set from the start of the scenario, the water demand of which will be around 5.3 Mm^3 in 2015 and 5.9 Mm^3 in 2020 represented by Figure 7, while in the reference scenario it is around 3.14 Mm^3. The latter continues to increase in 2050, so there will be a need for water more than 7.8 Mm^3 for an endowment of 150 dm^3 per inhabitant per day and more than 4.7 Mm^3 if the endowment is of the order of 90 dm^3 per inhabitant per day. In this case, there will be an unsatisfied quantity of water exceeding 2.7 Mm^3 in 2020, and more than 3.7 Mm^3 in 2030 and about 5.4 Mm^3 in 2050. This approach allows us to have the quantitative, environmental and socio- economic consequences highlighted in order to choose an integrated management plan. This plan will address issues related to integrated water resource management in the study area to avoid future food deficit.

- **Loss rate scenario (DTP)**

The water demand in the scenario of decrease in loss rate as shown in Figure 8 will reach the same value as that obtained in the reference scenario until the year 2010. As the water demand in Taoura is more than 3.3 Mm^3 in 2020, 3.5 in 2025 and 4.7 Mm^3 in 2050. So, the scenario of decreasing the rate of loss in the period 2010–2050 from 50% to 20%, allows us to completely satisfy the demand for water by the year 2026, the quantity of said water satisfaction gradually increases to 15.6 Mm^3 in 2030 in the scenario of a decrease in the loss rate. The latter was 1.42 Mm^3 in the baseline scenario. If the rate of loss reaches 20%, the demand for nominated water will reach 0.7 Mm^3 in 2050 compared to 2.2 Mm^3 in the reference scenario (loss estimated at more than 50%). Water stress begins to appear in the year 2027, where we will have a satisfaction rate of around 99% in 2030, 89% in 2040 and 85% in 2050. Indeed, the decrease in the rate of loss has allowed for satisfying the demand for water in a limited period.

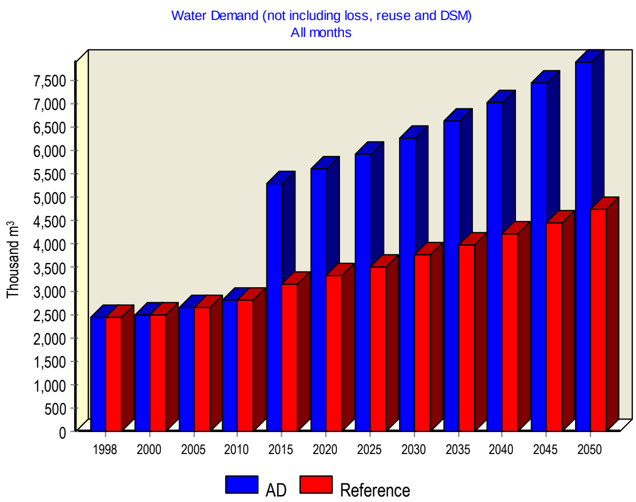

Fig. 7. Water demand scenario; source: own study

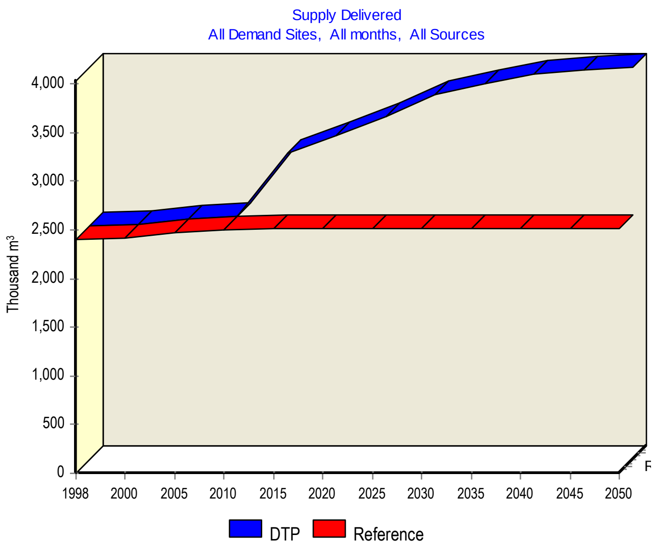

Fig. 8. Reduction in the loss rate (DTP) scenario water distribution; source: own study

- **Recovered rainwater use scenario (UEP)**

In this scenario represented by Figure 9, when we apply the rainwater recovery strategy in the study region in 2010, we observed that the amount of unsatisfied water gradually decreased compared to that obtained in the scenario referenced. Indeed, during the period 2010–2020, the water shortage gradually decreases to reach its minimum in 2025 at 97 Mm^3. From this year, the quantity of unsatisfied water continues to increase, reaching 800 Mm^3 in 2050.

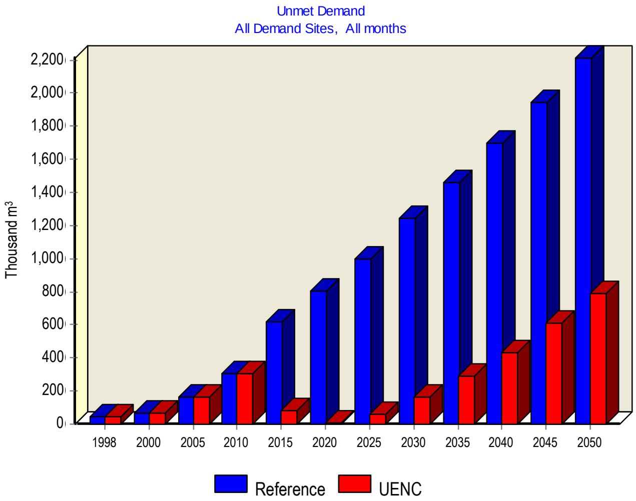

Fig. 9. The amount of unsatisfied water UENC scenario; source: own study

Our results confirm the success of this strategy. When the quantity of water not satisfied in the reference scenario and becomes more than 22 times that of which the result in this case, where the strategy of rainwater recovered for domestic use is used in the year 2025. It will reach 6 times more in 2030 and 2.5 times in 2050. In order to introduce this rainwater harvesting technology to the country, it is necessary to devise a strategy that encourages individuals to use it through grants and incentives from the state. We cite France as an example which gives a tax credit of 25% for individuals who uses this technique.

- **Increase in maximum groundwater withdrawal (APM)**

In this scenario where the deficit between the demand and the quantity of water distributed has intimidated to constitute an insurmountable handicap to socio-economic development. Given this water deficit where groundwater is partially exploited, the amount of unsatisfied water will be 0.3 Mm^3 in 2010, 1.4 in 2030 and 2.3 Mm^3 in 2050 (Fig. 10).

Paradoxically, if our underground water operations were made in a possible way, would have a deficit of water as shown on figure 10 such as from the year 2040 more in the weak month (0.347 Mm^3) compared to that obtained in the reference scenario (1.6 Mm^3). The scenario of increased maximum withdrawals of the aquifer of Taoura meets the objective sought by this study. Indeed, the lack of water in this scenario is noticed in the year 2040. Based on the results obtained in the preceding scenarios, such as the reduction of the rate of loss, the use of recovered rainwater and the increase in maximum groundwater withdrawal to achieve maximum exploitation, groundwater cannot satisfy the demand for domestic water in a rational way, especially in the case of the scenario of increasing the daily endowment in the long term in the Taoura Centre whatever the strategy is followed. These results enable us to ask the question: what happens if the various scenarios are applied together? That is to say, we build another scenario that combines the four scenarios proposed in this study. The latter is called the desirable scenario.

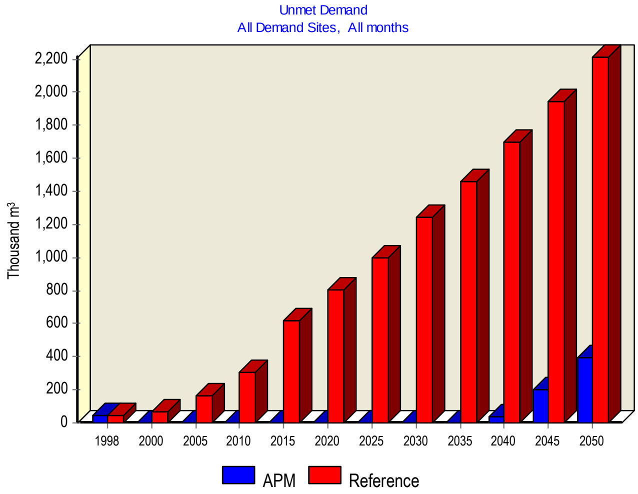

Fig. 10. The quantity of water not satisfied scenario; source: own study

- **The desirable scenario**

After having shown in the previous part the general characteristics of the different scenarios from the socio-economic, technological, hydrogeological and political point of view, so we can present and diagnose the result achieved in an application that combines the different scenarios proposed to achieve the objective of this study.

So, this scenario shows that the policy proposed in the desirable scenario in this study is the point of deviation from a techno-economic and social point of view to remedy the future water handicap and make the most of the underground resources existing in the region. Study with minimum cost and energy.

CONCLUSIONS

The current management of groundwater resources in the Taoura Centre is generally ineffective. Indeed, the results of the baseline scenario show that this sector of drinking water in the Taoura Centre did not experience sufficiently significant development. In addition, those responsible for water management placing the exploitation of surface waters (Ain Dalia dam) for the needs of drinking water as a first priority, had not given sufficient importance to the preservation of ecosystems in their actions to develop the water resources. Our results show that the reality is already tense. It absolutely requires more economical, more sustainable and more equitable water management.

These results are more or less analogous to the results obtained in this research. In which we noted that by 2025 the abutting water deficit affected more than 33% of the population of the Centre of Taoura, and in 2050, this deficit would reach 50% of the population.

This is why to provide solutions for the future water crisis, it is necessary to plan and follow a strict policy. Therefore, the baseline scenario is not the desirable discount scenario in the future for two reasons. The first is the results obtained represent a significant water handicap. The second is the remarkable global development in the social and water sectors and even technologies in this field, which is very far from our water policy. In this context, management and planning with other likely, feasible and desirable scenarios is a necessary step. In order to use the different scenarios and the strategies proposed in a single scenario, such as increasing the daily allocation, decreasing the rate of loss, recovering rainwater and increasing the maximum groundwater withdrawal, the water deficit noted previously in each scenario will be gone this time. Indeed, this strategy confirms that the lack of water in the study region is not a problem generally linked to the availability of fresh water, but it is a problem of management and organization between technology and the economy.

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