Water Supply and Purification

Sousse Scale, Tunisia

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Co-Evolve4BG

Analysis of Threats and Enabling Factors for Sustainable Tourism at Pilot Scale

Water Supply and Purification

Sousse scale, Tunisia

ANPE

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OVERVIEW

The present document was produced in the framework of Co-Evolve4BG project *"Co-evolution of coastal human activities & Med natural systems for sustainable tourism & Blue Growth in the Mediterranean"* in relation to Threats and Enabling Factors for maritime and coastal tourism development on a national scale" Co-funded by ENI CBC Med Programme (Grant Agreement A_B.4.4_0075).

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List of abbreviations

ANPE: National Agency for Environment Protection

APAL: Coastal Protection and Planning Agency

CRDA: Regional Commissariat for Agricultural Development

INS: National Institute of Statistics

ONAS: National Sanitation Office

OTEDD: Tunisian Observatory of Environment and Sustainable Development

PDUI: Integrated Urban Development Project

PNUD: United Nations Development Program

SONED: National company for the exploitation and distribution of water

Abstract

Various sources of water supply contribute to meeting the water needs of the Sousse region, including the coastal areas and tourist zones. Some of the key water sources include surface and subsurface resources with potential, of 48Mm^3 and 29Mm^3 respectively, and unconventional water with a potential of 16Mm^3. Agriculture is a major sector in terms of water demand (83%) followed by domestic use (11%) the industrial water needs, including manufacturing processes, cooling, and cleaning, also contribute to water demand. the tourism sector is a significant activity in Sousse, and hotels, resorts, and restaurants require a considerable amount of water between 3 and 6 Mm^{3}per year to meet the needs of visitors. Future water demand in Sousse is likely to increase due to factors such as population growth, urban expansion, and economic development Water management is facing a number of challenges as a result of population increase, urbanization, industrialisation, and climate change. Water quality contaminants such as untreated wastewater, industrial discharges, and untreated waste can contaminate freshwater sources and coastal water bodies, harming drinking water quality and aquatic ecosystems. More than 6.45 Mm^3 of all resources mobilized are kept in nappes with salinities varied between 1.5 and 5 g/l, affecting not only daily activities but also population health. The water supply system itself has the ability to pollute the environment. In reality, this network is already thriving in Sousse. This explains why sewers frequently overflow at specific pumping stations. of addition, the sanitary system of Sousse is the oldest in the region.

Given these obstacles, demand management becomes critical to ensuring long-term water supply. Water conservation with promotion of water conservation awareness among citizens and Encourage effective water use in families, industries, and agriculture through smarter technologies and practices are some techniques and measures to control water. Another method is to implement treatment systems to recycle treated wastewater for non-potable uses such as irrigation. The integration of water management principles into urban planning to optimize water resource use in urban development projects to achieve sustainable urban planning. Finally, enforcing norms and standards to monitor and control water use in diverse sectors is essential.

I. Introduction

Tunisia is one of the Mediterranean countries with the fewest water resources. His hydrological potential is characterized by an uneven geographic distribution and a significant annual variability. Tunisia belongs to the 17 countries throughout the world which will experience "absolute rarity" of the water resource by 2025. Due to numerous threats, the hydrographic capital is under severe stress; rising water extractions are approaching the scale of resource availability. With less than 315 m3/year per person by 2030. Tunisia's water resources are below the penury threshold. Hydrological stress has been increasing since the year 2000 as a result of a number of factors, including climate change, hydro-meteorological characteristics, rising demand, and inappropriate resource management.

A major challenge involving hydraulic resources is being faced by the governorate of Sousse, which is located on Tunisia's eastern coast. Sousse draws an increasing number of visitors each year thanks to its beautiful beaches, extensive cultural heritage, and contemporary infrastructure. But as the city becomes more well-known, there are significant challenges with regard to water supply and sewage treatment in the tourist areas. This already concerning scenario grows increasingly unsettling.

To support sustainable tourism development and guarantee a positive visitor experience, water is a crucial resource. In order to meet the demand for potable water, recreational activities like swimming pools and aqua parks, and the irrigation of green spaces and gardens, adequate water supply must be made. Additionally, it is essential to effectively manage used water in order to preserve the environmental water quality and reduce health risks.

This reality raises concerns about the management of water in the tourist areas of Sousse. To ensure long-term management of this essential resource, it is crucial to recognize current issues and anticipate future water needs. Therefore, the goal of this deliverable is to thoroughly study the issue of water availability and water treatment in Sousse's tourist areas.

In this deliverable, we'll start by analyzing the various water sources that Sousse has to offer, paying special attention to the coastal area and the tourist areas. In addition, we assess the region's current water demand by looking at the various uses of water and identifying consumption patterns. Next, we'll discuss the water management issues that Sousse has, including water leaks and difficulties with wastewater treatment.

We will then make recommendations for the best water management in Sousse. These recommendations aim to increase water availability, encourage more efficient water use in tourist areas, and strengthen the infrastructure for treatment used water.

This report will cover the following parts:

- The topographical, pluviometry and hydrological feature of the Sahel of Sousse
- Water resources in the Sousse region
- Identification of water management problems
- Different use of fresh water in Sousse region
- Evolution of the water demand in the future
- Strategy for better managing water resource in the Sousse region

II. The topographical, pluviometry and hydrological feature of the Sahel of Sousse

The study area is located between latitudes 35°35’ and 35°55’ in the north and between latitudes 10°20’ and 10°40’ in the east. The topography is composed of collines that are connected by grotesque valleys. The elevations become significant at the Kalâa Kebira collines (135 m above sea level), and thereafter gradually and occasionally inadvertently decrease toward the sea (Chouari, 2020). Overall, there aren’t many penalties, which don’t exceed 3% (Figure 1).

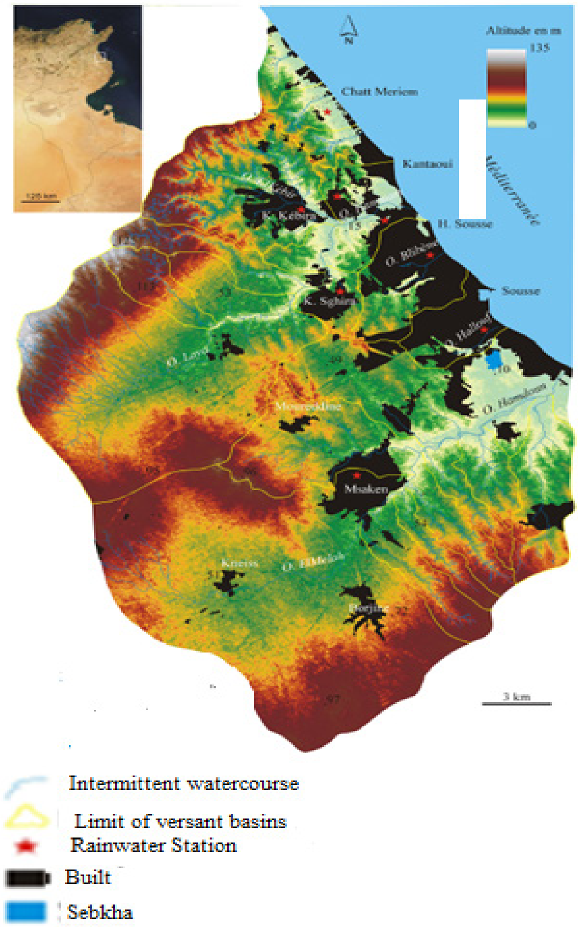


Figure 1. Location of the Sahel de Sousse and details of its topography and hydrology. Sources

an ASTER image (altitude data with global coverage, spatial resolution = 20m) and assembly of topographic maps of the 1988 type at 1/25,000. (Chouari, 2020)

The Sousse region is located at a semi-arid bioclimatic level below a harsh winter. With an average annual precipitation of 326 mm, the pluviometry recorded at the Sousse station is often irregular from one season to the next and from one year to the next. She varies in size between 31mm (1942–1943) and 910mm (1995–1996) (Chouari, 2020). But the rainstorms are frequently violent and torrential, they have the potential to develop into real torrents with strong winds that might cause inundations.

The varying shapes of the reversing basins make them not very dangerous in terms of how they respond to water. However, some quasi-circulatory impluviums cause a convergence of the flows in the direction of urbanized areas. The ouds ElKébir (affluent of rive left of the oud Laya-El Hammam), El Hammam, Blibène, and Hallouf have been calibrated and regularly adjusted in order to limit any overflow.

III. Water resources in the Sousse region

The sparsely populated and largely endorheic hydrographic network is thus strongly characterized by surface and subsurface resources that are constrained by local geographic and climatic factors. Water flows that manage to exit this area have a debit that is frequently low and fluctuating due to seasonal changes and precipitation altitudes. The treated water is presented as an intriguing and unconventional alternative to meet the region's expanding water needs. These water resources are still very underused today (Figure 2) (Sahout et al., 2015).

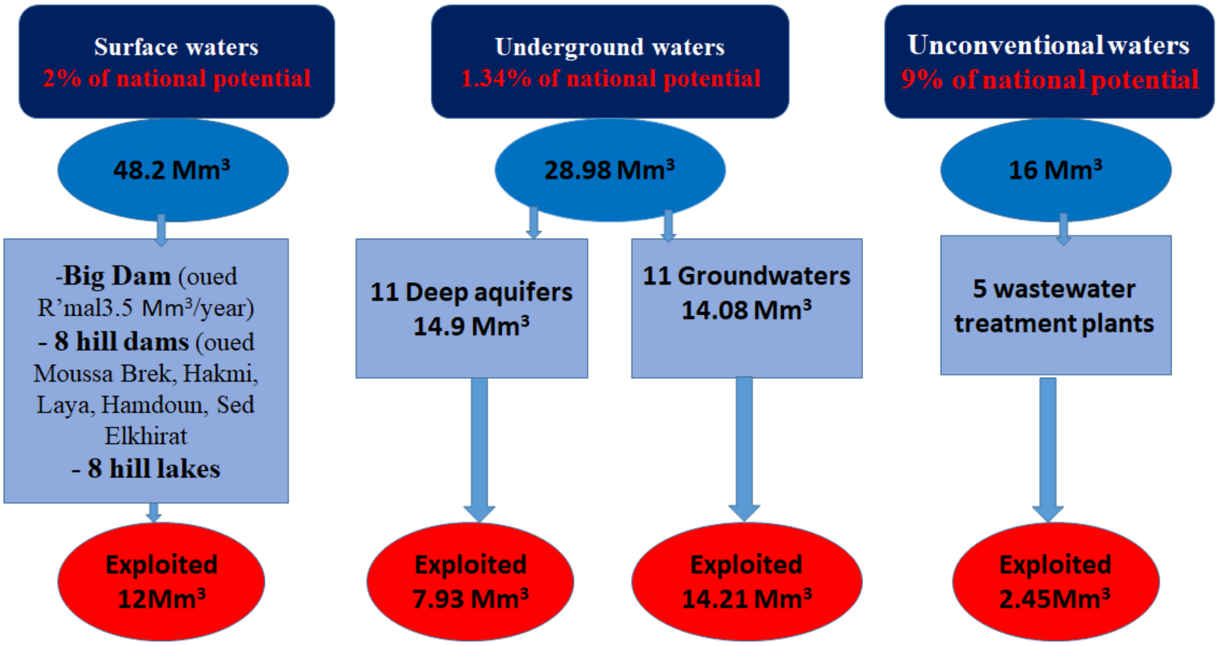


Figure 2. Organization chart of Local Water Resources of the Governorate of Sousse in 2005

III.1. Surface water

On the scale of the governorate of Sousse, the runoff water resources that can be mobilized are estimated at 50 million m³. These resources are mobilized up to 69% (34.4 million m³) (PDUI, 2020). Mobilization is made by the Oued Errmal dam (22 million m³ intended for irrigation), the hillside dam of Oued El-Khairat (8 million m³ intended for groundwater recharge and irrigation) (Table 1), in addition to hill lakes (PDUI, 2020).

Table 1. Chracteristics of the watershed of the area of Sousse

watercourse	Length (Km)	Area (Km^2)	Main tributaries	Flow in m^3/S decennial	Flow in m^3/S centennial	agglomerations crossed by the watercourse
Laya-El Hammam	14.5	219	O.El Kebir O. Kharroub OZebs	95	200	Kalaa Sghira, Kalaa Kbira Akoida et Hammam Sousse
Hamdoun El Melah	17.5	313	O.Chergui O.Deiik O. Grab	110	240	Msaken
Bliben	5.2	15	O.Kharroub O.Ghnim	40	85	Sousse Nord
Hallouf	4.5	12	O.Sidi Kasem O.Jebli	60	130	Sousse Riadh, Sousse Sidi Abdel Hamid

CRDA Sousse 2018

III.2. Groundwater

The region of Sousse has 11 groundwaters, the majority of which is renewable, with depths between 30 and 50 m. These 11 groundwaters which are distributed between the territory's north and west, have utilization rates that range from 42% to 125% (PDUI, 2020).

- The Chott Mariam aquifer extends over a totally urbanized area, and where agricultural activity is becoming less and less important.
- The Frada aquifer is characterized by highly charged water that is unusable for agriculture, which explains its low rate of exploitation.
- The Msaken Synclinal includes the layers of Msaken, Zaouia, Knaeis, Sousse Riadh and Sousse Medina and extends over the entire watershed of Oued Hamdoun. These aquifers present water of good to mediocre quality depending on the sector. These layers are highly stressed (160%) (PDUI, 2020).
- The Synclinal of Oued Laya shelters a layer which covers the delegations of Kalaa Kebira, Kalaa Sghira, Akouda and Hammam Sousse. It is characterized by its good water quality.
- The aquifers of the watersheds of the Hallouf and Blibene wadis are also exploited mainly by industries (Oued el Hallouf) or for domestic use (Oued Blibene) (Table 2).

Table 2. State of groundwater in the Sousse region

Groundwater	exploitable resources (Mm3/year)	resources exploited (Mm3/year)	exploitation rate (%)	equipped wells	abandoned wells	total number of wells
Bouficha	O.95	0.9	94.7	200	158	358
Synclinal de Oued Leya	3.3	3	90	546	237	783
Chott Meriem	0.8	1	125	198	65	263
Synclinal de Mseken	1.3	2.2	169	309	206	515
Frada	0.4	0.3	75	36	13	49
Sidi Saiden	0.35	0.35	100	65	68	133
Sidi ElHeni	0.5	0.3	60	30	20	50
Sakhet ElKalbia	1.3	1.1	84.6	132	55	187
Oued ElKhirat	0.95	0.4	42	76	41	117
Kondar	2.9	3.6	124	598	211	809
Chgarnia	1.8	2	111	278	111	389
Total	14.5	15.15	104	2,468	1,185	3,653

CRDA Sousse 2018

III. 3. Deep aquifers

The deep aquifer structures in the governorate of Sousse are for many of them located in the same formations as the water tables, which sometimes makes their separation more difficult. There are 11 deep aquifers in the Sousse region. They have depths between 50 and 350 m. Their resources are estimated at 15.9 Mm^3, 87% of which are exploited through the construction of 178 deep wells. Water quality is acceptable with a salinity of between 1 and 6 g/l (PDUI, 2020). The Oued El Khairat aquifer, which has the largest mobilized reserve, has an excessive salinity which varies between 1.5 and 5 g/l (Table 3).

Table 3. State of groundwater in the Sousse region

Deep aquifers	renewable resources (Mm3)	resources exploited (Mm3/Year)	Exploitation rate (%)	Number of wells	Salinity (g/L
Pilio-Quat Bouficha	0.5	1.12	224	24	1.6 -3.8
Calcaire Eocene Bouficha	0.5	0.22	44	4	0.9 -1.7
Knaies	0.5	0.55	110	19	1 -3
Kroussia	1.9	1.78	94	14	2.5- 6
Balaoum	0.4	1.45	362	56	1 -4
Draa Souatir	0.7	0.97	138	6	1 -5
Oued ElKhirat	5.6	8.62	154	26	1 -4
Chegarnia Sidi Abich	1.7	1.22	72	10	1.5- 3
Structure Mangoub Rmil	1	0.71	71	14	1 -3
Eocen Jbel Fadloun	1	0.18	18	1	1.5- 2
Jbel Garci	1	0.12	12	2	1-6
Total	14.90	17.021	114	176	1 -6

CRDA Sousse 2018

III.4. Unconventional waters

In addition to traditional waterways, the region also has access to filtered and desalinated water. On the one hand, the six treatment facilities that are present in the area and have a combined capacity of more than 33 million m^3 per year treat this water (Table 4).

A saltwater desalination plant with a yearly water production capacity of more than 35 million m^3 will also be installed in the Sousse region (PDUI, 2020).

Farmers in the area are hesitant to use treated waste water at the moment. Despite having six treatment stations that produce, on average, more than 44 650 m^3/j, or more than 16 Mm^3/an, this potential for used water, which is relatively significant given the region's need for agricultural water and could serve as an alternative, is still largely underused, with less than 3 Mm^3 of used water being recycled as of today (PDUI, 2020)

Table 4. Unconventional water potential in the governorate of Sousse

Station / Sector	Daily capacity (m3)	Annual capacity (m3)	volume exploited (m3)	Exploitation rate (%)	water use
Sousse Nord	30,000	10,950,000	1,137,000	10.4	sports field irrigation (112 ha)
Sousse Sud	30,000	10,950,000	784,325	7.1	Irrigated perimeter (Zaouet Sousse)
Msaken	7,850	2,865,250	311,000	10.9	Agricultural Irrigated perimeter
Mammamet Sud	20,000	7,300,000	2,482,000	34	Agricultural Irrigated perimeter
Kalaa Sghira	1,450	52,250	planned exploitation		
Sidi BouAli	1,750	642,400	planned exploitation		
Total	91,060	33,236,900			

CRDA Sousse 2018

Despite this diversity of resources, the question of water is thoughtfully raised in the context of the Greater Sousse region. This theme of water resources touches on a number of issues, including blue economy, sustainable economy, solid economy, and circular economy, and it is very important for ensuring sustainable agriculture.

IV. Different use of fresh water in Sousse region

The distribution of water consumption by sector in the given region reveals a striking disparity in water use among the various sectors. The agriculture sector emerges as the largest consumer, accounting for a staggering 83% (SONED, 2019) of the total water consumption (Figure 3). This finding is consistent with the fact that agriculture often demands substantial water resources for irrigation to support crop growth and maintain agricultural productivity. In contrast, Domestic appears to be the second significant water consumer, using approximately 11% of the available water (SONED, 2019). The tourism industry's water needs 1% for hotel operations, recreational activities, and maintaining amenities for tourists, especially in areas with high tourist inflow.

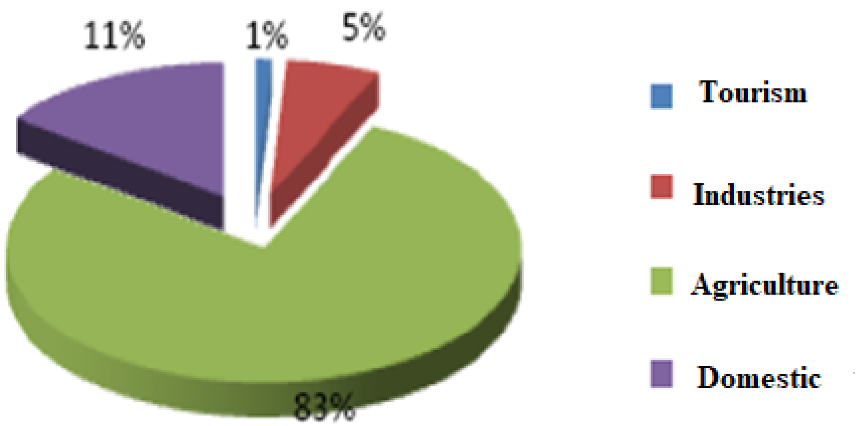


Figure 3. Breakdown of water demand by sector (SONED, 2019)

IV.1. High and diverse household consumption

Drinking water supply in the Sahel region is done mainly from Northern Waters (Sahel Tranche), surface waters processed from the Nebhana dam (Harkoussia, Ezzouhour and Znatir stations), from the Kairouan and Sbeïtla aquifer, Enfidha boreholes and independent management. The total production of the Sahel was 62.3% in surface water and 37.7 % from local groundwater (SONED, 2017). The volume consumed invoiced to the Center region reached 101.9 Mm^3. In 2017 against 96.9 Mm^3 in 2016, an increase of 5.2%. Thus, fluctuations by use varying between 0.8% for Industry and 17.4% for Tourism (SONED, 2017).

The increase in water consumption in the Grand Sousse is closely related to demographic growth, the dispersal of rural population surplus into cities, but also to the significant effort made by public authorities through the SONEDE to serve urban canter's that have not yet been fed and to generalize the distribution of freshwater to the entire population. In the Sousse Governorate, 99.9% of the population has access to drinkable water, with 95.2% of households having direct and individual connections to the SONEDE distribution network (Sahtout et al, 2016).

In addition to being staggering, the proportion of volumes consumed by connected households has significantly changed since the 1970s, the first years of the SONEDE's creation and the widespread adoption of networked branching, rising from 1,8 Mm³ in 1969 to nearly 20 Mm³ in 2007 (Figure. 4).

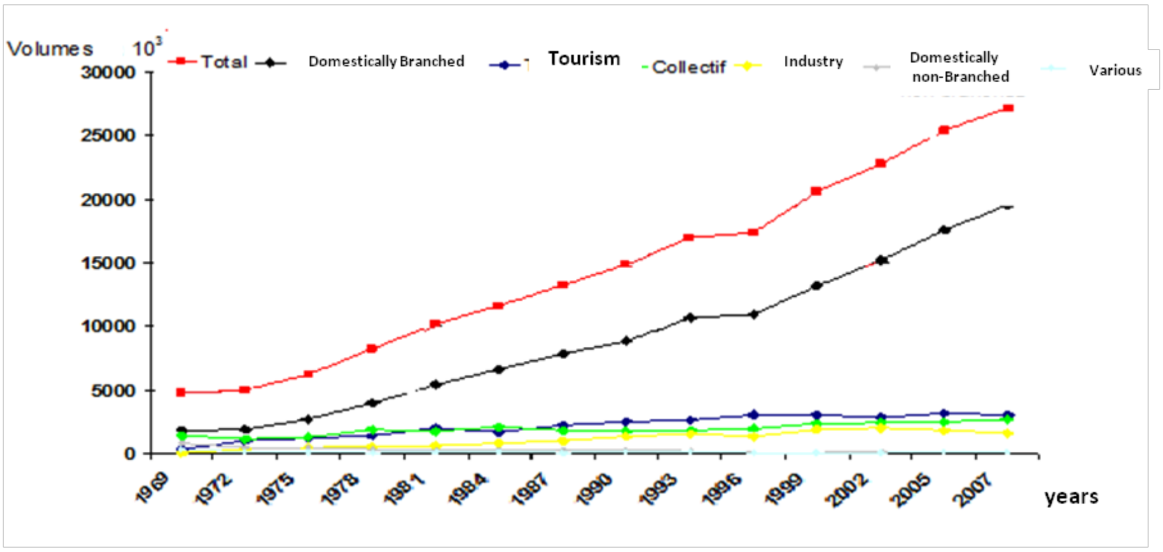


Figure 4. Evolution of water consumption in volume by type of user in the governorate of Sousse between 1969-2007 (Sahtout et al, 2016)

The representation of this consumption by administrative sector (Imada) enables to see that the consumption of households is most significant in urban areas, particularly that of the Grand Sousse, with 2007 consumption volumes ranging from 28,000 m³ to more than 1,000,000 m³ (Figure 5).

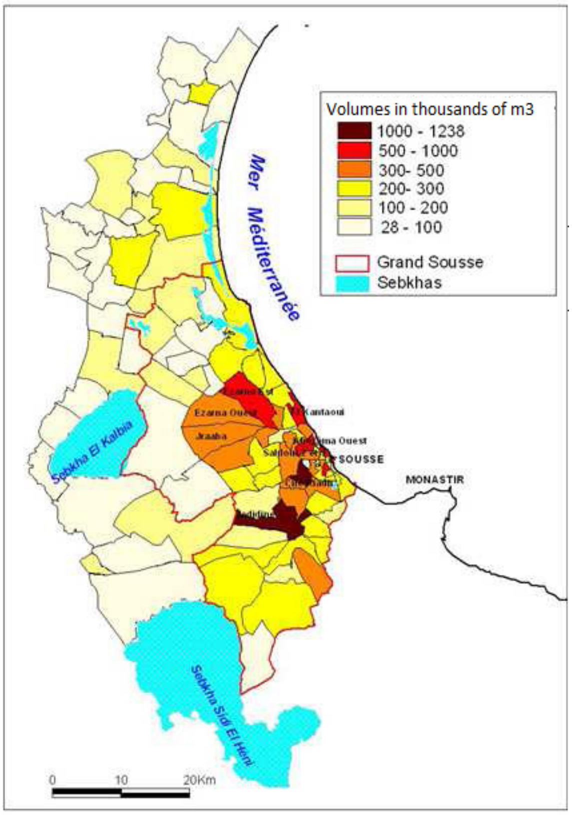
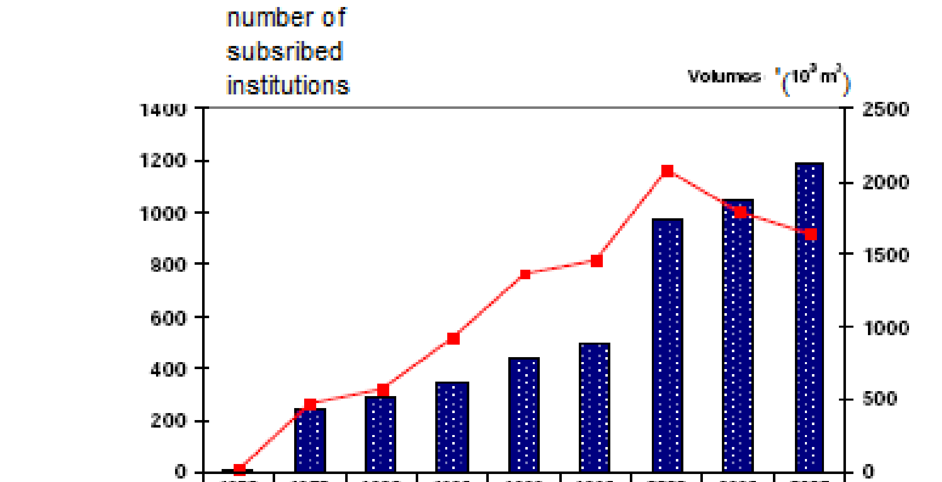


Figure 5. Water consumption by administrative sector (imada) in the governorate of Sousse in 2007(Sahtout et al, 2016)

The analysis of different consumption patterns at the sectoral level, the smallest administrative unit, reveals a social divide between wealthy, middle-class, and common neighborhoods, which is represented by specific consumption rates ranging from less than 50 liters per day per resident in the poorest areas to more than 500 liters per day per resident in the wealthier areas. This consumption disparity is related to the different levels of household equipment as well as to resource-saving or wasteful behaviors.

IV.2. Industry: a "large consumer" and polluter

The study area holds the second-most industrial establishments per square mile. The effects on the amounts of water consumed were immediate and progressed in the same way (Figure 6). In terms of distribution by Compared to other industry sectors, the "Agro-Food Industry" is the one that uses the most water. "Construction materials," "textiles," "chemistry," and "mechanics," etc. There has been an industrial growth. Undoubtedly a positive effect, as it has made the Sahel of Sousse one of the country's most active regions. However, its acceleration over the past decade and the concentration of businesses and industrial zones along the coastline have led to a greater threat of environmental deterioration, including the issue of sewage disposal and used water, and have created a grave threat to water resources that are already overused.



	1970	1975	1980	1985	1990	1995	2000	2005	2007
industry subscribes	7	241	294	349	444	497	977	1050	1190
consumption	19	476	571	925	1370	1459	2080	1794	1641

Figure 6. Evolution of consumption and the number of subscriber industrial establishments in the governorate of Sousse between 1970-2007

IV.3. Concentration seasonal of tourism-related activity

Even while tourism is a more recent competitor for the distribution of potable water in the Grand Sousse region, it doesn't appear to pose a threat to supply at this point, with 11% of total volumes of potable water consumed for less than 1% of subscribers. But in reality, he is a big consumer, which is why the vast majority of hotels are categorized as big consumers by the SONEDE due to their high consumption per sleeping unit.

A little over 3 Mm^3 of total water was consumed in 2007 by the tourism industry, distributed among just 123 subscribers, including 57 hotels. This represents a significant consumption in certain tourist areas, potentially exceeding more than 6 Mm^3 (Figure 7) up to more than 700 litres/day/bed. These water tensions are not so difficult to manage due to the importance of consumption, but because they tend to increase in the summer when water is sorely lacking, and when needs for tourism are intensifying with an increase in the number of overnight stays exceeding 1 million for the months of July, August and September. Hotel occupancy rates reaching peaks of 120%, while they average 58.6% (which is par elsewhere higher than the national average occupancy rate of 51.5%). This without taking into account that the alteration of the conditions climatic conditions has generated increasingly hot summers in recent years, which has the effect of increasing water requirements considerably, up to the tolerable limits of water stress (Sahtout et al., 2016).

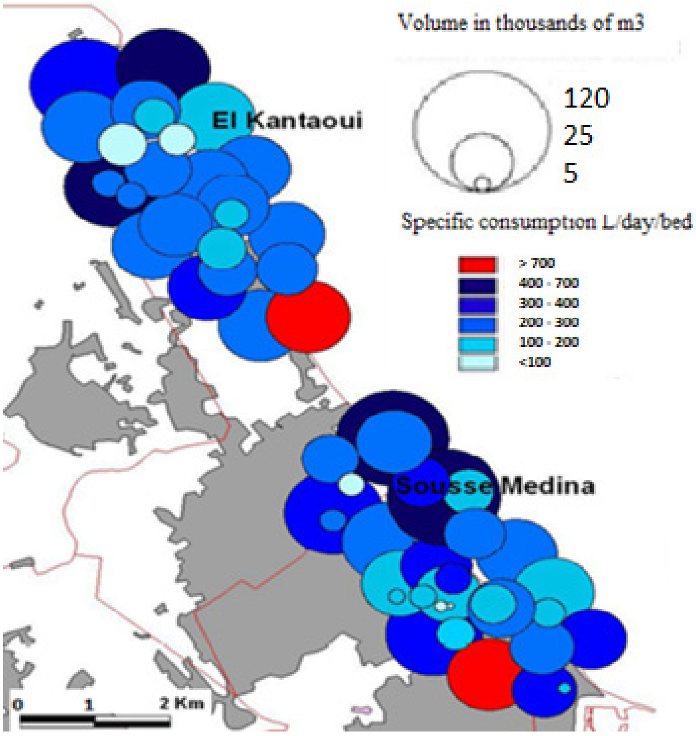


Figure 7. Water consumption by hotels in Grand Sousse in 2007

IV.4. Evolution of the water demand in the future

Our objective is to know through a systemic and prospective analysis, the possible evolutions of the relationship between populations, water resources, components of the environment and the sectors activities which are the pillars of regional development. The prospective scenarios show that we have to act today to confront the declining conventional resources during the next decades. A deceleration of this increase in the consumption does not seem inescapable. This is why developing an awareness of a better demand management is important. That implies an intensification of the campaign to raise public awareness and the development of a financial incentives (penalizing and, or encouraging) to inflect this request. According to this strategic scenario, the domestic and economic activities request should be reduced of almost 14 Mm^3 before 2034 (Sahtout et al., 2015). A choice of evolution rhythm was determinated for every variable (Figure.8). The outcomes of the prospective analysis show that integrated management would make it possible to realize a real inflection of the request for nearly 9% in the medium term (2024), and already 30% in the long term (2034).

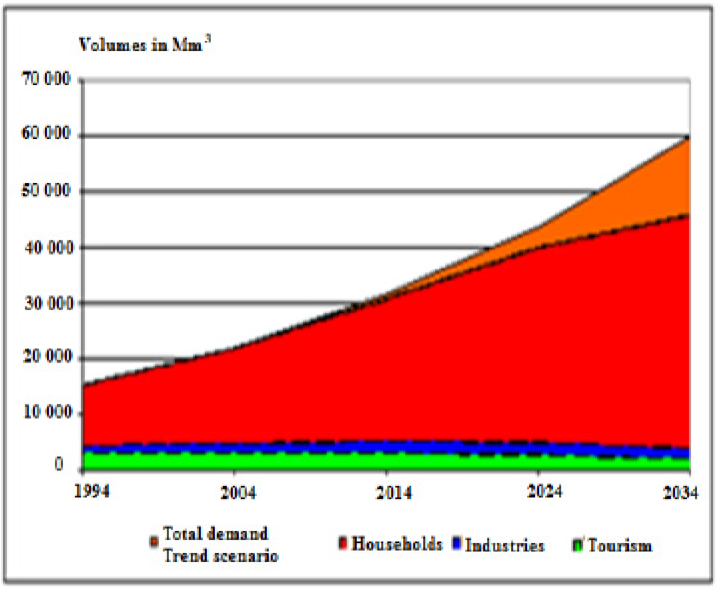


Figure 8. Evolution of the demand for total water between 1994 and 2034 (Sahtout et al., 2015)

V. Identification of water management problems

Climate change, as well as a number of other issues involving groundwater or others problems, could have an impact on water resources and management.

V.1. Hydrological poverty issues

The issue of water scarcity in Sousse region is long-standing. Different civilizations have long managed this scarce supply of water in central Tunisia in general and particularly in the Sahel region. Over time, they developed inventive methods for collecting rainwater, using local water resources, and transferring water between regions, making the region significantly more reliant on them for its supply.

A number of historical factors, along with modern factors related to the region's recent development, are the root causes of the Sousse's acute water resource problem.

The topographic factors

have an effect on water resources, reducing potential for ecology. The topographical conditions, in conjunction with semi-arid climate conditions, have resulted in a sparse and largely endorheic hydrographic network, which has a low potential for surface resources and even subterranean resources that could benefit from runoff.

Climate factors

have an equal impact on water resources due to their weak, erratic precipitation patterns and high evaporative powers. The Grand Sousse region is located in the isohyete range between 300 and 400 mm. Sousse region is distinguished by a significant regional variation in annual precipitation rates that decreases significantly from the north to the south and from the coast to the interior: 380 mm in Enfidha in the north-east and 343 mm at Sousse in the south-east. The pluviometer currently measures 285 mm at Kondar, which is located in the governorate's interior zone, and 271 mm at Sebkha Sidi El Hani located in western territory. It rains very irregularly from one year to the other, with average amounts varying by up to five times or more. The majority of the pluviometric contributions occur in the fall and winter, accounting for 42% and 37,5% of annual rainfall, respectively. The rainy season lasts from September through May for a short period of time, usually between 50 and 70 days. Summer is distinguished in particular by its warmth and drought.

Geographical factors

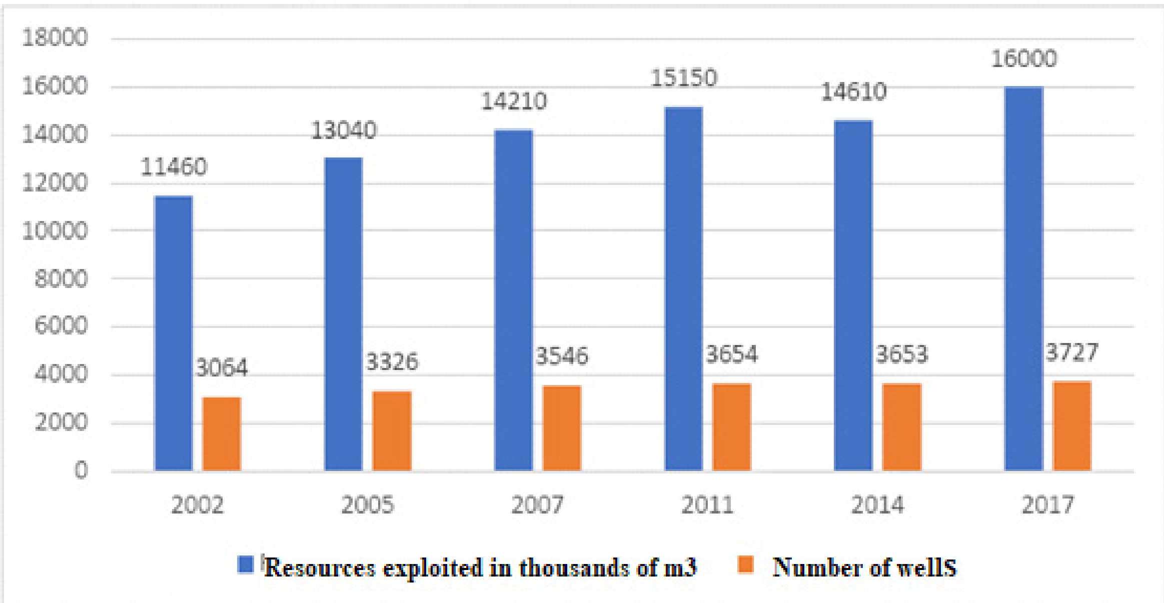
The fact that many of the deep aquifer structures in the Sousse governorate are located in the same formations as groundwater makes dissociation from them occasionally more difficult. Currently, the potential is in the range of 14,9 Mm^3/year, however only 53% of these resources are being fully used. In 2005, the amount of pumped water was 7,93 Mm^3 compared to the volume exploited in 1993 which was just 5.47 Mm^3, however there was a considerable improvement in the use of this nappe due to the quick evolution of demand, particularly in urban areas.

Anthropological factors

A notable urban expansion and demographic growth was observed in Sousse region. Consequently, it has a tendency to become a focal point for the region's major water-intensive consumption industries, including irrigated agriculture, manufacturing, and tourism. These activities serve as the region's economic pillars. Due to imbalances between the supply and demand for water in this region, a factor once thought to be essential to the long-term sustainability of urban growth and economic expansion has now turned into a constraining factor for development, particularly in agriculture. In fact, the growth of economic activities, separated from agriculture, causes the peak in demand to occur during the hot season. This already coincides with the peak in demand for both agricultural and touristic activities.

The pressure on some groundwater reserve is faster and more intense than their capacity for renewal through the deep percolation of runoff water. This intensification was caused by the quick increase of well drilling. Additionally, the quantity of unexploited wells suggests overexploitation, which is translated into a local abatement of some groundwater. Farmers have increasingly anarchic drilling practices (Figure 9).

The managers of the water sector are tasked with finding solutions to ensure the best balance between meeting the demands of various sectors while not jeopardizing the needs of the agricultural sector, which is also at the pinnacle of its needs, in these circumstances, particularly in the context of total dependence and severe water resource scarcity.



CDDA Sousse 2018

Figure 9. Evolution of groundwater exploitation and number of wells in the Sousse region between 2011 and 2017.

V.2. Water quality declining

The water quality in the Sousse region is declining both in terms of salinity and hydric contamination, which affects not only daily activities but also the health of the population. In the majority of groundwater, the chemical quality of the waters is rated as average. It is estimated that 6.45 Mm^3 or 44.3% of all resources that can be mobilized are stored in nappes with salinities greater than 4 g/l. This salinity is even more significant as one approaches the coastline and as the wetlands are overused, has resulted in saline invasions and in a decline in piezometric level (Sahtout et al.,2015) (Figure 10).

Physical-chemical investigations show a nationwide non-conformity rate of 5% for Tunisian waters, with a higher rate in the Sousse region of 13%. The pollutants that have exceeded regulatory limits include nitrates, sulfates, chlorures, dust, turbidity, electrical conductivity, and pH.

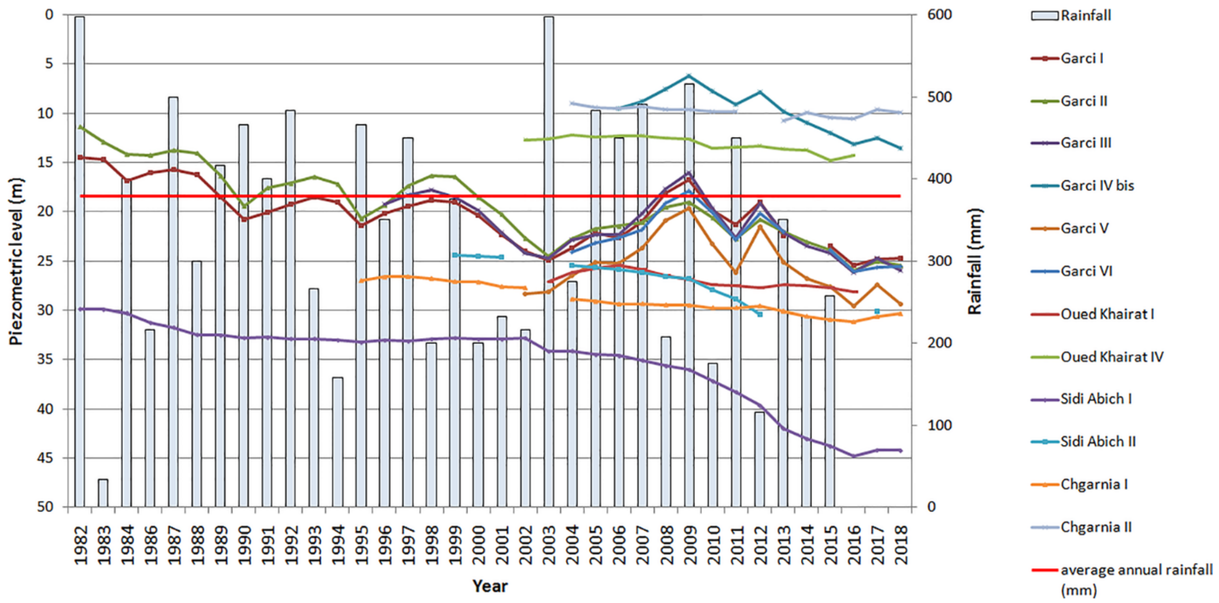


Figure 10. Piezometric level and annual rainfall variability in the Enfidha region with time between 1982-2018

According to a comparison of the quality parameters of groundwater with Tunisian norms and World Human Organization (WHO) guidelines, the majority of groundwater samples are unfit for human consumption (Table 5). Significant health risks result from nitrate contamination of the groundwater. In fact, 45% of samples have nitrate concentrations over the 50 mg/l, 90% of samples have Chloride concentration over than 250 mg/l, 90% of samples have Magnesium concentration over 30 mg/l and 75% of samples have Sodium over 200 mg/l maximum allowed by the World Health Organization. The excessive use of pesticides, chemical fertilizers, and domestic waste in irrigated areas may be the cause of this high ions concentration. the determination of the water quality index(DWQI) shows that only 30% of the groundwater samples of Enfidha are of drinking quality (Kammoun et al.,2022).

Table 5. Drinking water quality standards

Parameters	pH	EC	TDS	Ca2+	Mg2+	Na+	K+	HCO3-	SO42-	Cl-	NO3-	Mn2+	Fe2+
WHO standards	6.5 - 8.5	1.5	600	200	30	200	30	380	250	250	50	0.4	-
% Samples exeeding standard	0	85	100	35	90	75	0	15	70	95	45	0	-

For the bacteriological analyses, they show a Tunisian national average rate of non-compliance of 16%. In Sousse, there is a high rate of bacteriological non-compliance of (24%). The absence or ineffectiveness of disinfection operations was noted by high rates of absence of free residual chlorine recorded in Sousse. Discharges of treated wastewater contributes to this bacteriological contamination of water.

The degradation of sewage waters quality and the pollution problem: Similar to the majority of Tunisia's major urban areas, the pollution of urban and coastal waters prior to their embouchure in the Grand Sousse is primarily the result of domestic and industrial discharges, whether or not they have passed through a purification station. Particular sources of industrial pollution include the Sidi Abdelhamid area and a few rivers that flow into the sea, like the Hamdoun and Laya rivers in Sousse. In addition, many entire suburban neighborhoods lack a system for collecting and transporting used water, and they instead discharge their waste water into the environment without any treatment.

For many years, at the beginning of each summer, the Ministry of Health has taken used to proclaim several Tunisian beaches unsuitable for swimming following organic and chemical pollution that exceeds the standards. The very and formerly urbanized coasts come first, including some of Grand Sousse.

In this case, the coastal waters of the Sidi Abdelhamid area, receiving warm waters discharged by the thermal power plant (Figure 11), suffer from a deterioration in their quality with the manifestation of several signs of pollution, loss of biodiversity.

The trampling of constructions, especially anarchic, along the coast, so as to disrupt the natural balance of the coastal environment. Abuses are always at risk of occurring on the coastline of Sousse which is still just as coveted, especially for tourist activities.

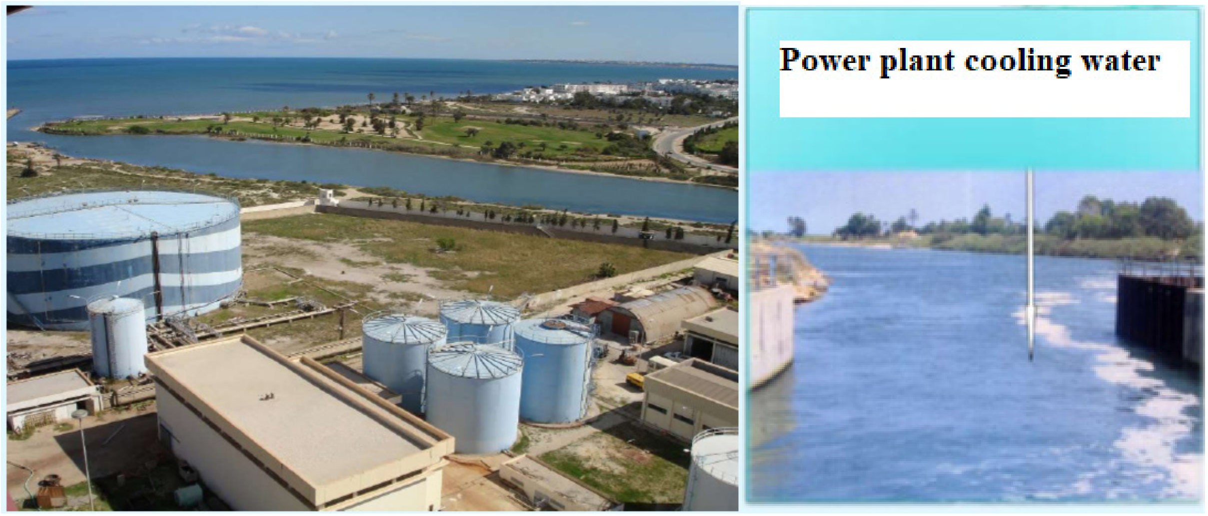


Figure 11. Sidi Abdelhamid's power plant

V.3. Water losses

Accidental water leaks are a major problem in the Sousse region, with serious consequences. These leaks in water distribution systems squander a significant amount of precious water resources. They not only lead to wasteful water consumption, but they also have significant financial ramifications for municipal governments in charge of water management. Furthermore, these leaks interrupt network pressure, disrupting the consistent supply of water to households, businesses, and critical infrastructure.

according to SONED statistics between 2010 and 2015there was a noticeable trend of increased water losses in Tunisia, with values going from 99.5 to 169.1 Mm^3/year. In 2017, the total water losses increased at a rate of 10.8% to be at the level of 221.3 Mm^3 (SONED, 2017) This pattern appears to be closely tied to the concurrent population rise during the same time period. According to the data, as the population has grown, so have the water losses. This could be due to a number of issues, including aging infrastructure, increased demand for water services, and difficulties in maintaining and improving water distribution networks to serve the growing population. and secure an adequate and dependable water supply for both the current and future populations. The calculation the structural index of water distribution leaks during the year 2017 indicates a value of 2.4 for the region of Grand Sousse (SONED, 2019).

VI. Damage caused by wastewater discharges

Currently, the ONAS covers the entirety of the Grand Sousse in terms of sanitation, but the rate of connection varies in some rural areas. Whole suburban neighborhoods lack a network for collecting and transporting used water, and instead discharge their waste water directly into the receiving environment (oueds, sebkhas, etc.) without any treatment. In the Sousse Governorate, 14 out of 16 communes are managed by the ONAS network, with a global branching rate above 90% but hovering around 75% in rural areas. Sousse, Hammam Sousse, Kalaa Kebira, Kalaa Sghira, Akouda, M'saken, Hergla, Messaadine, Sidi Bou Ali, Enfidha, Ksibet-Thrayet, Zaouiet-Sousse, Ezzouhour, and Bouficha are the communities taken under management. Six purification stations are located inside the Sousse government.

The water supply system itself has the potential to become a source of pollution. In fact, this network is already booming in the city of Sousse. This explains the common overflow of sewers at certain pumping stations. Added to this is the fact that the sanitation system in Sousse is the oldest in the region. It was built in the 1950s.

The STEP Sousse Sud primarily handles the treatment of the city's used waters. However, in addition to those from Hammam Sousse, Kalaa Kébira, and Akouda, the STEP Sousse Nord also receives used waters produced at the level of a portion of the tourist area from Sahloul and Blibène. The indicator for the "quantity of water actually treated by treatment capacity" shows that the STEP Sousse South is over used while the STEP Sousse Nord is getting close to operating at its peak efficiency. When combined with other factors, overexploitation of purification facilities has negative effects on the final quality of purified water.

On the other hand, the ONAS's used treated water doesn't always produce the desired results. For instance, the Oued Hallouf (Figure 12) currently serves as a drainage canal for treated waste water that is discharged from the Sousse South purification plant. The same stream travels through the city of El Matar and is subject to discharges of raw sewage from pump stations, especially during periods of heavy rain. It also picks up significant amounts of domestic and animal waste. The pollution caused by Oued Hallouf reaching the sea at the level of Gaied Souassi beach makes the area unsuitable for swimming. A problem with water stagnation that is causing foul odors to emanate from the lower portion of the river is noted.

Figure 12. Obstruction of the oued Hallouf and lack of cleaning

Thrayet, Messaadine, Ksibet Sousse, and Sousse are all traversed by the Oued Hamdoun, also known as the Oued El Maleh in Msaken. He lands on the water just north of the Monastir Governorate's boundary. Oued Hamdoun receives continuously used domestic and industrial water, as well as runoff from other rivers and agricultural drainage water rich in azote, phosphore, and heavy metals. Multiple sources supply the waters used to discharge into the Oued basin (Figure 13).

Figure 13: Discharge for treated wastewater in Oued Hamdoun Sidi Abdel Hamid and Hammam Sousse

VII. Strategy for better managing water resource in the Sousse region

Based on the assessment of the hydrological resource condition in the Grand Sousse region, the strategy for managing and using the water will need to integrate a number of approaches.

VII.1. Surface water mobilization

This strategy aims to fully mobilize surface waters in order to meet urban water needs, enhance coastal city water quality, and meet existing and planned agricultural needs.

The optimization of retention basins: Since there are not many waterways in the Grand Sousse region, the amount of surface waters is limited, making it challenging to gather them. Additionally, more than 80% of the mobilization of these surface waters occurs in the north and northwest of the governorate, or in the south-eastern piedmonts of the most recent Dorsale faults. These resources are primarily made up of contributions from the region's only large barrage, El Rmal, whose storage capacity is 295 Mm^3. However, his average annual contribution is only 3.5 Mm^3 (PDUI, 2020)

In this portion of the territory of the Grand Sousse's northwest, smaller barrages collect surface water, it involves the hillside dams of Oued Kheirat, Oued Moussa, Oued Brek, and Oued Hakmin, which mobilize 5; 1.2; 1; and 0.26 Mm^3 respectively. These structures function as real locks for the collection of water from rivers.

Increase the amount of reserves available for mobilization by building ten collinear barrages at the same level as the governorate's other small watercourses, such as Oued Laya, Oued Hamdoun, and Oued Essed, which have capacities of 0.5 ;1; 0 and 0.5 Mm^3, respectively.

Station of Sahel treatment and separation of the transport networks for treated and untreated Northern Waters

VII.2. Groundwater recharge and water soil conservation

One of the proposed and adopted solutions entails recharging the groundwater and aquifers, particularly those that are near the locations of the barrages. Due to the crues' lamination and orientation toward the nappes, this recharge of subterranean nappes occurs naturally through infiltration. This is the specific example of the Breck hillside dam. The barrage's leakage water flows into the aquifer below, maintaining the nappe's piezometric level and ensuring its ongoing use. More than ten wells have been built on the two Breck River tributaries, 1.5 kilometers away from the barrage (PDUI, 2020).

This groundwater recharge method offers additional unintended benefits as well. It serves as a preventative measure against the containment of harmful substances that could otherwise endanger the environment. Approximately one-third of the water amassed through these initiatives naturally permeates the soil, contributing to the nourishment of groundwater and deep aquifers. Within the Sousse region, these hydraulic endeavours primarily cater to hydro-agricultural needs, situated roughly 1.5 km upstream from the dam. Furthermore, they play a vital role in safeguarding and conserving both the land and water resources.

This function of lakes and hill dams is equally applicable to those that surround Sousse and the cities that make up the Grand Sousse. By safeguarding people and property, they also play a significant part in the prevention of invasion and the reduction of flood risks. In the event of an inundation, the dam amortizes the debris in proportion to its storage capacity, performs evacuation duties via the evacuator, and protects the landslide zones as a result. There is some degree of this function of battling inundation on every onslaught. However, taking into account how close the agglomerations are, an appropriate strategy for managing the water must be put in place to reduce the risk of depletion in the event of excessive rainfall phenomena.

VII.3. Strengthening water saving programs

Increasing the effectiveness of water distribution networks by lowering*:* the amount of water lost during transportation. The most prominent efforts that need to be made at this level are mostly in the areas of potable water distribution and irrigation water distribution.

The improvement of water use levels in terms of productivity and output. When it comes to this element of increasing water productivity and yield, the focus will mostly be on the agricultural sector, which is a major consumer of water. It is here that modern irrigation techniques will be promoted and made more widely available (ANPE/OTEDD, 2009).

The improvement of recovering water costs: The improvement of recovering water costs frequently appears directly as a tool for managing demand and indirectly as a tool for water conservation.

Rainwater recovery: The recovery of urban rainwater is a very effective way to manage water stress and reduce consumption of mains water, but also to limit runoff and reduce the negative effects of soil sealing related to constructions. To this end, Decree No. 171 of February 19, 2018 obliges promoters of civil buildings to build rainwater collection tarpaulins (Figure 14). This text also regulates the construction and operation of these rainwater collection and storage tanks. These strategies should be used by major tourist destinations in order to gather rainwater (ANPE/OTEDD, 2009).

The real cost of water encourages consumers to practice frugal habits in an effort to lower their income from consumption. Currently, the pricing structure in place does not reflect all costs, including those associated with technical, environmental, and hydrological plans.

Figure 14. Rainwater collection cistern system

VII.4. Adaptation to climate change

Water saving is an essential component of the long-term strategy in the Sousse region. It is supposed to develop in order to minimize water losses at all levels, from the water source to the place of consumption and maximize its level of exploitation. Eencourage the use of traditional water collection and irrigation systems, including the Meskats', traditional method (Mahjoub et al., 2015). The climate of the Grand Sousse region is not particularly conducive to fluvial cultures. Semi-aridity and the inadequate pluviometry have long encouraged local inhabitants, particularly in rural areas, to develop innovative methods for the collection and rational use of water resources. In actuality, the ancient impluvium system known as "Meskat" (Figure 15) represents tools that allow for the harvesting of rainwater, the valuing of difficult-to-exploit land, and the planting of olive trees there. This system involves using the collinear surface as an impluvium (Ben Salem et al., 2021). The most frequently used irrigation water is used to grow olive trees in buckets or at the base of walls.

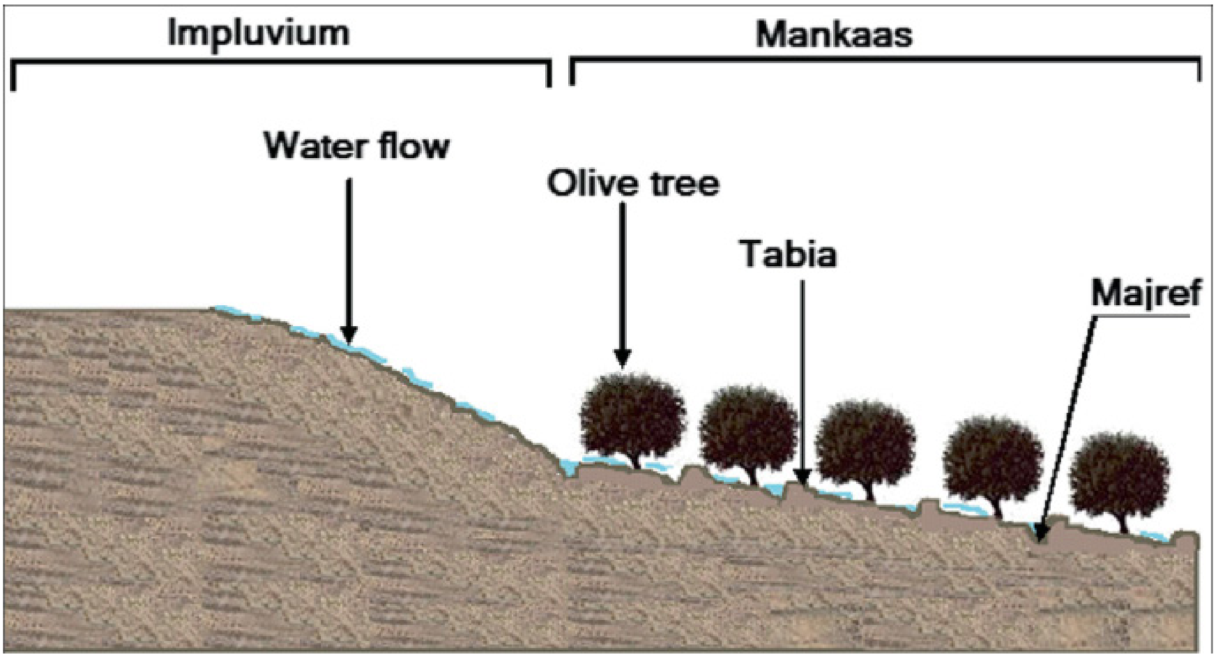


Figure 15. Spatio-Temporal Monitoring of the Meskat System Distribution (Ben Salem et al., 2021)

The ability to manage water using long oblique pipes allows for uninterrupted flow of water up to the level of the trees. The Meskats have contributed in an effective way to the upkeep of the olive growing in the governorate as well as to the decrease in the likelihood of soil hydric erosion thanks to the maintenance of surface waters.

VII.5. Exploitation of unconventional water resources.

In order to ensure an integrated management of the available water resources, development of non-conventional waters is required to meet present and future needs, preserve existing resources, and meet existing obligations.

Promotion and development of marine water desalination

the construction of the seawater desalination plant in Sidi Abdelhamid will be completed in the end of 2023 (Figure16). The plant will be commissioned in two phases. In its first phase, the future plant will have a daily capacity of 50,000 m^3 per day. The production of drinking water will increase to 100,000 m^3 per day with the second phase. This will be the culmination of a project launched in 2018 (SONED, 2019).

Figure 16. Water desalination station in Sousse (Sidi Abdel Hamid)

Valuing the use of recycled treated waste water: Despite the monetary incentives given in this area and the establishment and development of a dessert infrastructure, particularly at the level of irrigated perimeters, the reutilization of treated used water, at around 20% (Rapport de l'eau, 2021), continues to fall far short of expectations.

In fact, the rate of reusing treated agricultural wastewater as well as at the level of public green spaces and golf courses (Figure 17) is still quite low. The analysis has shown that the various potential users of treated water exhibit some reluctance when it comes to the resource's dependability from both a quantitative and a qualitative standpoint (Rapport de l'eau, 2021).

Figure 17. Use of treated wastewater in golf courses irrigation in El Kantaoui

Additional efforts could be made to improve the level of treatment of water used at the tertiary level, prevent contamination of groundwater and promote the use of treated water for irrigation and artificial recharge of certain overexploited agricultural lands. in order to stop the salinization of the bevels, as well as to encourage the unexploited sector to manage a few small desalination units.

VII.6. Integration of the ecological dimension in the water system

The Improving scientific knowledge regarding ecological water requirements is of utmost importance in addressing the growing concerns of water scarcity and environmental degradation. Ecological water needs refer to the quantity and quality of water necessary to maintain the health and integrity of ecosystems, which are essential for sustaining biodiversity and ecological services. By enhancing our understanding of these requirements, we can develop more informed and targeted water management strategies that prioritize ecological balance and long-term sustainability. Robust scientific research and monitoring programs can help identify ecologically sensitive areas and vulnerable species, guiding policymakers and water managers in making well-informed decisions (ANPE/OTEDD, 2009). Moreover, integrating ecological water needs into water allocation plans ensures that adequate flows are maintained in rivers, wetlands, and other critical habitats, safeguarding the delicate balance between human water consumption and ecosystem health. Emphasizing the improvement of scientific knowledge in this domain is paramount for fostering harmonious coexistence between human societies and the natural environment, ultimately securing a more resilient and thriving planet for future generations.

VIII. Conclusion

The water resource dynamics of the Grand Sousse region are characterized by a complex interplay of natural and anthropogenic factors that influence water availability, quality, and distribution. This in-depth analysis digs into the complex hydrological, topographical, and climatic forces that shape the region's water landscape. Analysing surface water sources reveals limited potential due to geography and climatic trends, prompting recommendations for optimizing retention basins and building more barrages to improve water capture.

Groundwater, a critical supply of water, necessitates smart management measures to combat overexploitation and pollution. The Breck hillside dam exemplifies the unique groundwater recharge strategy, which has the ability to replenish aquifers while also delivering other benefits like as environmental preservation and hydro-agricultural support.

Water loss has emerged as a critical concern, with a significant rise necessitating immediate action through infrastructure upgrades and leak detection techniques. Pollution exacerbates the problems, demanding extensive remedies ranging from improved sanitation to severe discharge laws. Water consumption is unevenly distributed across sectors, emphasizing the need for sustainable irrigation techniques, equitable distribution, and responsible water management in the increasing industrial and tourism sectors.

To negotiate these complications, the area must take a comprehensive and adaptable approach. Policy changes, technical advancements, and community involvement emerge as essential drivers of long-term water resource management. The Grand Sousse region can set the way for resilient water systems that balance economic growth and environmental preservation by merging ancient wisdom with modern solutions.

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