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Sustainability impact assessment of seawater desalination plant of Djerba in the southeast of Tunisia

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Abstract - Desalination of seawater has been chosen in Tunisia as a strategic response to the problem of insufficient water resources. However, this solution may be accompanied by negative effects on the environment.
The aim of this paper is to assess Sustainability impacts of seawater desalination plant of Djerba two years after its start-up. The qualitative and quantitative data were collected in face-to-face interviews conducted with stakeholders involved in water resources management at local and regional level. Collected data covers the period from 2015 to 2020. Sustainability impact assessment of seawater desalination plant is based on a set of social, economic and environmental indicators in the region. Main results showed positive impacts of the desalination plant with a net increase of drinking water supply and an improvement of the drinking water quality in the island of Djerba. However, the high energy requirements of the desalination plant (13.6% of the total electrical energy consumption in the region) and the important quantity of discharged brine (58 tons/day) rise concerns about negative impacts on the environment.

Key words: Water availability, Environmental impacts, Indicators, Energy consumption.

1. Introduction

Water scarcity is a major problem in Tunisia. With per capita renewable water availability of 450m^3, the country is below the absolutely water stress threshold set at 500m^3/yr/person by the water stress index (Falkenmark et al, 1989). Population growth, urbanization, economic development and climate change are the key driving forces that affect water availability. According to the strategic study of the Water Sector by 2050 for Tunisia (African Water Facility, 2016), potential conventional water resource for the whole country is estimated at 4,840 MCM/ yr, of which 2,700 MCM/ yr (55%) are surface water and 2,140 Mm^3 (45%) are ground water.). Substantial imbalances exist in terms of water availability between the humid north of the country that contains 83% of surface water and 31% of groundwater, the semi-arid center with 12% of surface water and 25%of ground water and the arid South with 5% of surface water and 44% of groundwater. The main water uses are irrigated agriculture sector (2,150 Mm^3/year,79%), drinking water (420 Mm^3,15%), industry (145 Mm^3,3%) and tourism (35 Mm^3,1%). Since independence, Tunisia has developed strategies for water resources mobilization. Construction of 34 dams with a storage capacity of 5 Mm^3, 234 hill dams with 1 to 5 Mm^3 storage capacity, 800 hill lakes with storage capacity less than one Mm^3 and more than 100,000 recharge wells allowed the mobilization of 90% exploitable water resources.
This mobilization of fresh water strategy has achieved its limit. Thereby, orientation towards a strategy of unconventional water resources mobilizing became essential to meet the increased water demand. The desalination experience in Tunisia started in the 1980s with the desalination of brackish water with the aim of improving the quality of drinking water in certain urban agglomerations in the South-East (Gabes, Zarzis), and in the islands (Kerkennah and Djerba). The total desalination capacity for drinking use is estimated at 59,000 m^3/day with an annual production of around of 15 Mm^3. In the industrial and tourist sector, around a hundred desalination stations allow a daily production of 35,000 m^3/day (African Water Facility, 2016). The seawater desalination experience was initiated in 2015, totally five seawater desalination plants was planned. The first plant located in Djerba became functional in 2018. The produced water with a good chemical quality is used mainly for drinking purpose. However, aside from the costs, there are other potential externalities associated with desalination facilities, including environmental impacts. Thus, a periodic sustainability impact assessment of the desalination plants is required. This paper provides an assessment of the seawater desalination plant impacts on socioeconomic and environmental levels/aspects at Djerba island two years after its start-up. First, it assesses whether the water accessibility improvement in the region and the reduction of the intersectoral competition on water supply. Furthermore, it evaluates the environmental impacts

regarding energy consumption and disposal of brines by the comparison of the indicators of sustainability impact, measured for both situations before and after the project.

2. Methods

2.1 Case study: the seawater desalination plant of Djerba

Djerba island is located in the governorate of Mednine (south east of Tunisia). It has an area of 514 Km^2 with flat earth and very low altitude, only 55 meters at maximum above sea level (Delmas 1952).
The mean annual precipitation is ranging from 150 to 200 mm. Most precipitation occurs between September and January with an average monthly precipitation of 30 mm. The driest time of the year is from June to August (National Institute of Meteorology, 2021). Community water systems (CWS) organization in Djerba is quite complex. It relies on:
i) Runoff water collected in cisterns,
ii) Overexploited phreatic aquifers,
iii) The deep saltwater table, the resources of which are desalinated plant of saline groundwater. This plant has a capacity of 15,000 m^3/day.
iv) The water transfer from Zeus-Koutine water table. This water, with a salinity level close to 3.0g/l, is mixed with fresh water from water desalination plant.

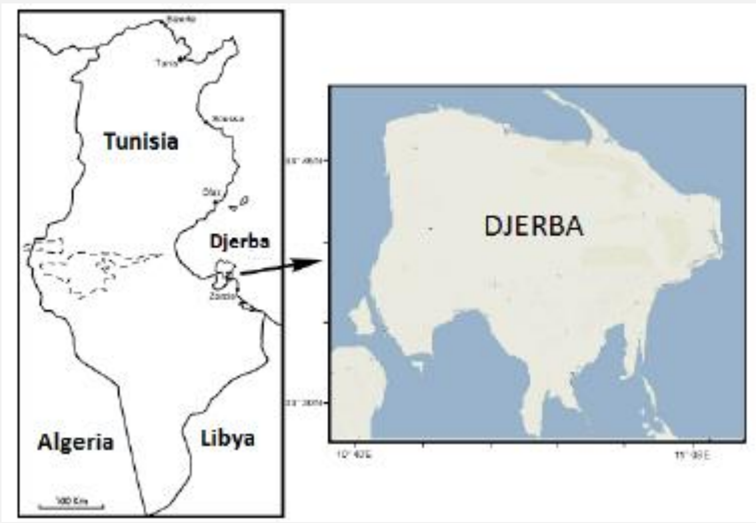

Figure 1: The island of Djerba- Tunisia
Source: Bouchahmaand Yan (2012)

Indeed, the total water availability reaches 605 liters/second, or 52,000m^3/day (SONEDE, 2015). Water demand projection, based on the assumption of 100% supply rate for drinking water and an annual increase of tourism sector water demand by 2.2%, showed a significant gap between water supply and water demand. This gab reached 12,000 m^3/day before construction of the seawater desalination plant which aims improving the water security and quality. The chosen desalination technique is reverse osmosis, which is based on a molecular-scale separation process, using a selective membrane subjected to a pressure gradient. Indeed, a reverse osmosis installation is based mainly on the application of pressure within a set of reverse osmosis modules thus allowing the passage of desalinated water through the membranes. However, in order to preserve the membrane from any form of degradation, conditioning is essential and it depends on the chemical composition of the water and the operating conditions of the installation. Also, the desalinated water being practically free of salts, is aggressive and requires treatment to restore its balance and also disinfection before it is dispensed. Desalination plant is made up of three phases: the pre-treatment phase, the reverse osmosis phase and the post-processing phase. To reach the initial level of production, the station should take from the sea 111,112 m^3/day to produce 50,000 m^3/day of desalinated water at a salinity of around 40 g/l and 61,112 m^3/day (55%) of discharge in the form of brine at a salinity of approximately 73 g/l. In addition, the discharged brine is characterized by high concentrations of metals, in particular Sulfate or Magnesium ions which need to be evaluated. In fact, the latter come from the initial raw water which was concentrated following the desalination operation. In particular, the concentration of sulfate ions in raw seawater is itself higher than the standard for discharge into the marine environment. Although the consumption per m^3 of desalinated water by reverse osmosis is low and the trend is constantly decreasing, the energy component remains, as in other processes, the most important in the structure of the production cost of desalinated water.

In comparison with thermal desalination systems, the energy consumption for reverse osmosis varies between 3.2 and 3.6 kWh / m3, depending on the size of the equipment and the mode of energy recovery. Taking into account the pumping for the seawater pipe as well as the auxiliaries, consumption was estimated at around 4.5 kWh / m3 during the planning stage of the project (SONEDE, 2015).

2.2. Sustainability impact assessment

As described by the Organization for Economic Cooperation and Development OECD (2010), the sustainability impact assessment is an approach for exploring the combined economic, environmental and social impacts of a range of proposed policies, programs, strategies and action plans. SIA can be seen as a tool for exposing the most significant positives and negatives impacts of projects rather than providing a final answer to the project evaluation (Laedre et al. 2015). According to the OECD (2010), SIA is a policy decision making tool, and not a substitute for it whatever the choice of method. In the last decade, SIA indicators have gained a particular interest. According to Pulzl et al (2011), the indicator development process is subdivided into two phases. The first phase consists of the definition and selection of indicators. During the second phase, indicators are (re-)defined according to the chosen quantitative tool requirements. As stated by Laedre et al (2015), the most well-known indicator frameworks in use for sustainability assessment and presentation are based on the Pressure-State-Response (PSR) framework developed by the OECD. This framework is based on the causal link between pressures on the environment, the modification of quality and quantity of natural resources and the societal response to these changes through environmental and economic policies. Sustainability indicators can be defined for each phase of this causal process. Thus, we distinguish the indicators of environmental pressures, indicators of natural resources state and response indicators. For water resources issue, core OECD indicators include intensity of use of water resources and share of discharged wastewater in rivers for environmental pressure. Frequency, duration and extent of water shortages are used as environmental conditions indicators. Indicators of societal responses include either measures constraining the quantities of water available or measures increasing the price of water to encourage efficient use. Desalination process which became widely used in solving water shortage may be considered as societal response for water resources issue. Indeed, sea water desalination may provide additional resources of water to meet increasing demand and consequently mitigate the extend of water shortages. However, desalination plants rise concerns about potential negative impacts on the environment. Einav et al (2002) identify five domains that may be concerned: the use of the land, the groundwater, the marine environment, noise pollution, and the intensified use of energy. Also, Lattemann S. and Hopner T. (2007) who studied environmental impact of seawater desalination mentioned that Key issues are the concentrate and chemical discharges to the marine environment, the emissions of air pollutants and the energy demand of the processes. Many other studies raised the same environmental issues (Einav and Loekiec 2003; Sadhwani et al. 2005; Dawoud and Al Mulla 2012). The major findings of these studies are that most impacts are linked to the brine returned to the sea with a high concentration of salt and several chemical products used in the desalination process. Furthermore, an important indirectenvironmental impact is related to the use of the energy required by desalination plants. Thus, a desalination plant can have several sustainable impacts in economic, social and environmental terms. Some impacts are positive related mainly to water availability improvement while others are negative (energy consumption and the effect on the marine environment). The following table lists used indicators in this study to assess the most significant impacts of the Djerba desalination plant.

Table 1. Sustainability impact assessment indicators

Economic indicators	Social indicators	Environmental indicators
Water transfer Quantities of water transferred from the Zeuss-Koutine water table to Djerba **Energy consumption** – Energy consumption per m3 of desalinated water. – Annual evolution of energy consumption in the Djerba area.	**Water quality parameters** Parameters of the natural structure of water (mg/l): • Dry residue • Chloride • Sulfate Undesirable parameters (mg/l): Nitrate Nitrite Organoleptic parameter (Nephelometric Turbidity Unit NTU): Turbidity	**Water stress** Gap between annual water needs and the distributed quantity **Brine discharge** Location of brine discharge (length of the outfall) Quantity of brine discharged per day (in tons) Respect of Tunisian waste rejection standards

The impact assessment is based on the comparison of the evolution of these indicators between the pre-project and post-project situations.

2.3. Data collection

Necessary data for the calculation of the impact assessment indicators were collected from the various stakeholders involved within the framework of the project. Interviews were carried out with Regional Commissariat for Agricultural Development, Tunisian Electricity and Gas Company and National Company for Water Exploitation and Distribution (SONEDE). The collected data covers the period from 2015 to 2020.

3. Results and Discussions

The selected sustainability indicators were measured over the period 2015-2018 covering a period of 3 years before the project and 3 years after its start. The sustainability impact of the desalination plant is assessed by the evolution of the indicators selected over these 2 sub-periods.

3.1 Water stress

The drinking water demand in Djerba increased significantly during the last decades. This increase is due mainly to the population growth, the modification of domestic practices and the improvement of living conditions, the development of tourist activities and to the development of industrial activity.
However, this zone does not have enough fresh water to meet the growing needs. Table 2 below shows that during the pre-project phase, the island's drinking water demand exceeded water supply provided by the SONEDE.

Table 2: Comparison between annual needs and the quantity of water distributed before and after the construction of the desalination plant

Year	Drinking water requirement	Drinking water distributed by SONEDE	Gap
2015	16,5	15,4	1,2
2016	16,5	15,5	1,0
2017	17,0	15,8	1,2
2018	18,0	18,1	-0,1
2019	20,0	20,8	-0,8
2020	21,5	21,3	0,2

The collected data show a recovery in the drinking water balance after the completion of the desalination plant since the quantities of drinking water distributed by SONEDE exceed the annual needs of the region.

3.2 Water transfer

In addition to the positive impact of seawater desalination on the quantity of drinking water distributed in the island of Djerba, another positive effect can be observed on the availability of drinking water in other neighboring regions. Indeed, the start-up of the desalination plant has enabled the significant reduction in the quantity of water transferred from the Zeuss-Koutine water table to the Djerba area, as shown in Figure 2.

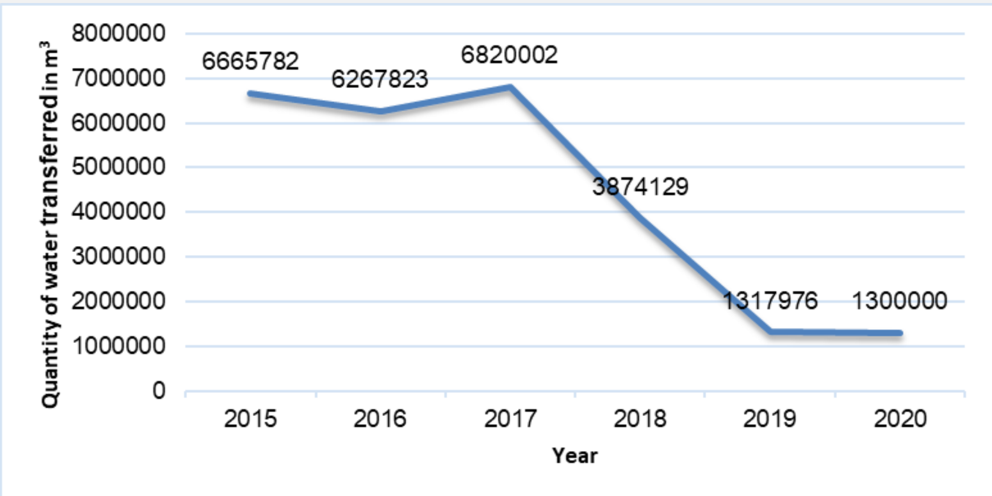

Figure 2: Water transferred from the Zeuss-Koutine water table to the Djerba

The figure 1 shows that after the construction of the seawater desalination, plant quantity of water transferred from the Zeuss-Koutine aquifer to the island of Djerba decreased by 5 million m^3. The decrease in the quantities transferred to the island of Djerba has allowed an increase in transfers to neighboring regions such as Ben Guerden and Zarzis which have benefited from an increase in the quantities transferred by around 2 million m^3 for each region.

3.3 Water quality parameters

In addition to improving quantities of drinking water in the region, the results showed that the desalination plant also made a significant improvement in the quality of drinking water. In fact, the comparison of the qualitative composition of the drinking water distributed before and after the completion of the station shows that all the parameters are within the Tunisian quality standards.

Table 3 shows that there is a qualitative improvement for the different types of analytical parameters of distributed drinking water (organoleptic parameters, parameters related to the natural structure of the water, undesirable parameters). In fact, the desalination of seawater enabled the dry residue to be reduced from 2,150 mg / l in 2015 to 480 mg / l in 2020.

Also, the sulphate taste threshold has significantly improved. This is because a high concentration of sulphate can cause harmful physiological effects such as gastrointestinal irritation and purgation. Thus, the presence of a large amount of sulfate causes dehydration and gives an unwanted taste. The results show that the sulphate content, which was around 750 mg / l in 2015 (well above the quality standard) has dropped considerably in 2020 to only 10 mg / l. Also, we notice the same evolution for several other parameters such

Table 3: Qualitative comparison of few parameters of drinking water before and after construction of the station

Parameters	Content in 2015	Content in 2018	Quality reference NT09.14-2013
Parameters of the natural structure of water			
Dry residue (mg / l)	2150	480	200 < Dry residue <2000
Chloride (mg / l)	702	265	500
Sulphate (mg / l)	750	10	500
Undesirable parameters			
Nitrate (mg / l)	3.5	<0.5	45
Nitrite (mg/l)	0.015	<0.01	0.2
Organoleptic parameter			
Turbidity (NTU)	0.85	0.17	3

3.4 Energy consumption

- Energy consumption per m^3 of desalinated water

The water desalination processes can be classified into two main families. Thermal processes and separation by membranes or reverse osmosis. The desalination process adopted in the seawater desalination station of Djerba is reverse osmosis. Although this process allows a much lower energy consumption compared to thermal processes, the energy consumption is still high due to the needs for pumping, transfers and treatment of desalinated water.

The results indicated that the amount of energy consumed to produce one m^3 of desalinated water in the Djerba seawater desalination plant is of the order of 2.58 KWh/m^3. Consequently, the production of 50,000 m^3/day of desalinated water requires the consumption of 129,000 KWh / day.

This indicates that large-scale desalination requires significant amounts of electrical energy. Table 3 shows a consequent change in the amount of energy consumed by the island of Djerba after the construction of the desalination plant. This result indicates that the desalination of seawater which allows the resolution of the problems of water scarcity can create energy problems if this experience is generalized in several regions, especially if the energy used is non-renewable as is the case with the Djerba plant.

Table 4: Annual evolution of energy consumption in the Djerba area before and after the construction of the desalination plant

Year	2015	2016	2017	2018	2019
Annual energy consumption (MWh)	276,101	260,433	273,042	313,660	347,224

In addition, the increase in the consumption of electrical energy for the needs of desalination plants is of growing concern for the environment due to the expected amount of pollution by emissions of gases.

3.5 Brine discharge impacts

Discharge of concentrated brine in large quantities calls for more careful consideration of the potential environmental impacts. The results of our study indicated that from the quantities of seawater pumped, the Djerba seawater desalination plant produces 46% of desalinated water and releases 54% of brine.

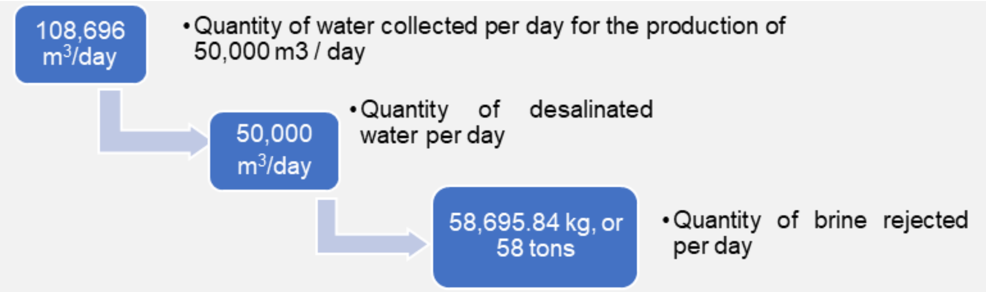

Figure 3: Quantity of brine discharged per day in tons

The discharge of brine in high concentration and insufficient dilution can deplete or destroy aquatic ecosystems. Apart from the volume itself, the manner and location of the discharge are critical for any impacts that may result. According to Scoutter et al (2007) the length of the outfall, its distance from the shore, its level above the seabed, the existence or not of a diffuser, as well as the depth of the water and the hydrological characteristics (currents, waves), can condition the dispersion of the brine and the efficiency of the dilution at the point of discharge and therefore the potential impact on the environment. To minimize the impact of discharge on the environment, the Djerba seawater desalination station uses a pipe 4,900 m long (of which 2,300 m are on land and 2,600 m are at sea) and 1,500 mm width. Despite the fact that the desalination station has planned long pipes to carry out the rejects in depth, it remains essential to monitor the composition of this brine in advance to avoid a deterioration of the marine space. The table 4 shows that the chemical compositions of the brine comply with Tunisian discharge standards.

Table 5: Comparison of physicochemical and bacteriological analyzes with Tunisian waste rejection standards

Analyzed parameters	**Tunisian standards for rejection in the Public Maritime Domain**	**Physicochemical composition of brine**
Temperature measured at the sampling time in degrees Celsius	35	In summer: 30,5 In winter: 22
pH	$6.5<pH<8.5$	8.1
Suspended matter (SS) in mg / l	30	19

We should specify that this evaluation takes place only 2 years after the start-up of the plant. This short period may not be sufficient to notice a change in the composition of the marine space. It is therefore important to periodically monitor the evolution of this composition to ensure that it continue to comply with the Tunisian standards.

Conclusion

Water resources in Djerba island are scarce and fragile. An important increase in the demand for water has been observed in recent years. This has necessitated the use of seawater desalination technology to meet the increasing needs of the population for drinking water and to solve the problem of water scarcity. The first seawater desalination plant located in Djerba became functional in 2018.

This study was carried out two years after the implementation of the Djerba seawater desalination station in order to assess the impact of this project on improving the drinking water supply in the region. It also aims to assess the environmental effects of the plant's installation, mainly with regard to its energy requirements and the composition of the brine discharged into the sea.

The obtained results showed that the quality of the drinking water in the island of Djerba was improved through several parameters. It enabled the reduction in the quantity of water transferred by the Zeus Koutin aquifer to Djerba by 80% compared to the quantity transferred before the construction of the seawater desalination plant. The positive impacts of the Djerba desalination plant have gone beyond the implantation area since the reduction in pressure on the Zeuss-Koutine water table has made it possible to improve transfers to ben Guerden and Zarzis. In addition, the results of this study showed that the environmental issues are important since the energy requirements of the station are high. In fact, the electrical energy consumption of the Djerba seawater desalination plant represents about 14% of the region's total electrical energy consumption. Also, the desalination plant is responsible for the release of a large quantity of brine amounting to 58 tones/day. Despite the fact that the desalination station has planned long pipes to carry out the rejects in depth, it remains essential to monitor the composition of this brine in advance to avoid a deterioration of the marine space.

Given that the prevailing climate changes in Tunisia refer to an aggravation of the water stress situation, the solution of seawater desalination could become inevitable. The Djerba desalination plant is the first stage in a program that should enable the construction of several other stations in different regions. Consequently, it remains essential to choose, for future installations, desalination processes that take into account environmental challenges both in terms of energy consumption and the protection of marine space. At this level, it has been proven that photovoltaic systems remain the most economical option until this horizon. In addition, brine treatment technologies seem to be a promising option to eliminate the wastewater discharge. This can be achieved through minimal liquid discharge (MLD) and zero liquid discharge (ZLD) strategies.

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