Pollution and Anthropogenic Pressures Affecting Ecosystems

Djerba Scale, Tunisia

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Co-Evolve4BG

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

Pollution and other anthropogenic pressures affecting ecosystems

Djerba scale, Tunisia

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OVERVIEW

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REVIEW

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Abstract

It is obvious that the island of Djerba is highly affected by anthropogenic activities that extend over its coastal areas and affect different areas. The problem of pollution should be investigated since Tourism represent the main economic activity of the island. According to previous studies conducted in 2018, tourism was responsible for about 57% of wastewater and 25% of solid waste. In fact, within this small area of about 514 km^2, there are about fifty hotels, three fishing ports and a very large urban area. Thus, the threats facing the island are numerous. They are mainly related to sewage discharge as well as to solid waste. Their impact on temporary landfills seems to be drastic. Pollution indicators are used to measure the extent and impact of these threats.

I. Introduction

In Tunisia, the main problems threatening coastal areas are mainly the water quality and marine pollution, especially in the south of the country. In addition to these two problems, the management of solid waste is a new concern that needs to be studied.

Coastal marine pollution can be caused by various sources, such as the discharge of domestic and industrial wastewater in the areas of major tourist cities, agricultural drainage, and stormwater drainage from major urban tourist areas. Solid waste dumping and air pollution are also considered as potential threats. In addition, traffic off the Tunisian coast in this region is dominated by oil tankers.

Pollution in coastal areas could have several negative consequences leading to the prohibition of bathing in certain coastal tourist areas due to the deterioration of seawater quality. Other negative impacts include damage to biological resources, threats to human health, and impediments to maritime activities, including fishing. Therefore, it is necessary for the Tunisian authorities to intervene in this area and implement a policy to combat this type of pollution.

Although the need to protect habitats and species has been established in both quantitative and qualitative terms, the tools to diagnose their health have not been defined yet. Monitoring environmental quality can be realized thanks to two approaches: (i) the detection of pollutants and their quantification; (ii) the assessment of the impact of pollutants on living organisms, either at the level of individuals or at the level of populations and communities. There are many indicators that respond to environmental perturbations at different time scales. The research and use of multi-proxy indicators is an answer to an essentially applied problem, ecosystems bio-assessment and predictive diagnosis of their spatial-temporal evolution. Currently, it is possible to measure biological impacts from the cellular level to populations and ecosystems.

In fact, an ecosystem approach is essential to have a deep critical level. At this level, we can identify the threats in a very specific ecosystem based on good marine spatial planning. Considering the specificity of Djerba island with several coastal sites, namely an extensive urban area, a large tourist area, three fishing ports (fishing port of Houmet Souk, the fishing port of Aghir and the fishing port of Ajim), among which, one is used for yachting.

II. Main sources of pollution in Djerba

II.1. Salinization of the water table

The water resources potential in this region is modest. The island has a variable and irregular rainfall regime. The average annual rainfall is about 200 mm. It should be noted that Djerba has no surface water system (stream, lake, river ...). In fact, in the island subsoil, there are only two aquifers: a shallow aquifer and a second-deep aquifer. The aquifer accounts for 7% of the water resources on the island. The average depth of this aquifer is about 30 m. The available resources are estimated at about 3.47 Mm^3 with an exploitation of 3.61 Mm^3, resulting in a negative balance. Moreover, water salinity is estimated at 0.5 g/L in the center of the island. In the coastal areas, the salinity increases and exceeds 5 g/L(Fig. 1)(Souid et al 2017). This water table is currently overused, and the risks of seawater intrusion and pollution are very high.

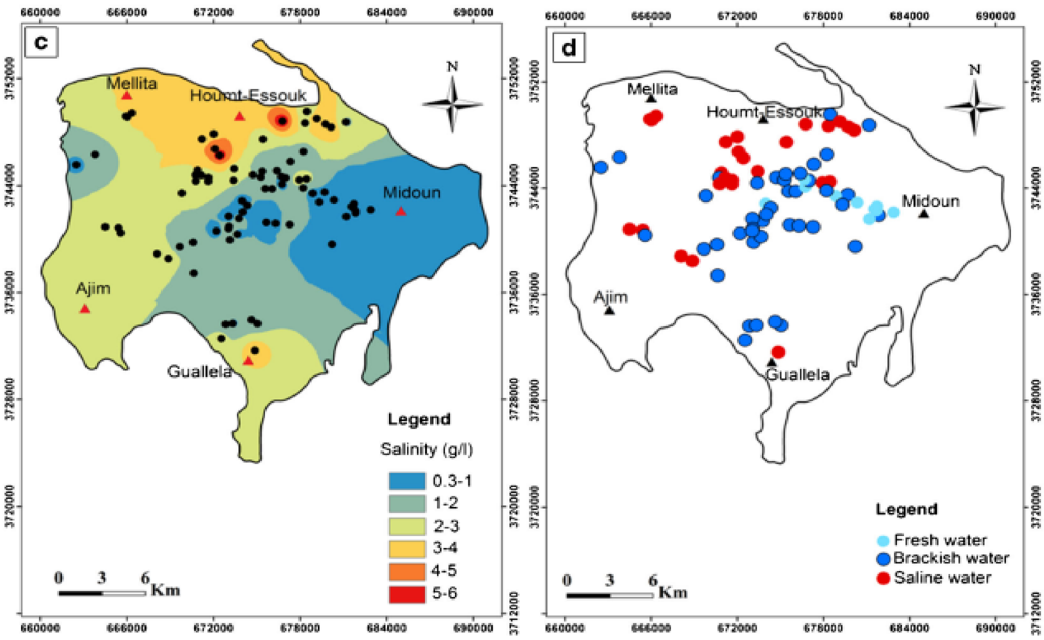


Figure 1. Spatial distribution maps for the Salinity concentrations (Souid et al 2017)

The deepwater table, which extends between Skhira in the north and the Tunisian-Libyan border in the southeast, represents 48% of the island's water resources. The groundwater resources of this water table are estimated at about 22.08 million m^3. It is used by the desalination plant for brackish water from boreholes from 250 m to 350 m deep. The water salinity varies between 5.5 and 6.5 g/L. For drinking water supply, the Djerbian population uses cisterns (commonly called fsegui) equipped with an impluvium for collecting rainwater and a perfectly dug reservoir that protects the collected water reserves from evaporation and provides drinking water to the population at any time of the year.

In some parts of the island, the underground water of the water table is used by traditional wells. These wells are characterized by typical architecture that is still preserved on the island. The water points inventory has revealed the presence of 2,321 surface wells. Besides, irresponsible human activities are one of the threats to the water table of Djerba. The undeveloped septic tanks and "garbage" wells are the source of the water table contamination due to the infiltration of water rich in pollutants. The direct contact of some waste pits with the water table greatly favors the transfer of pollutants to the groundwater and fecal contamination (Fig. 2).

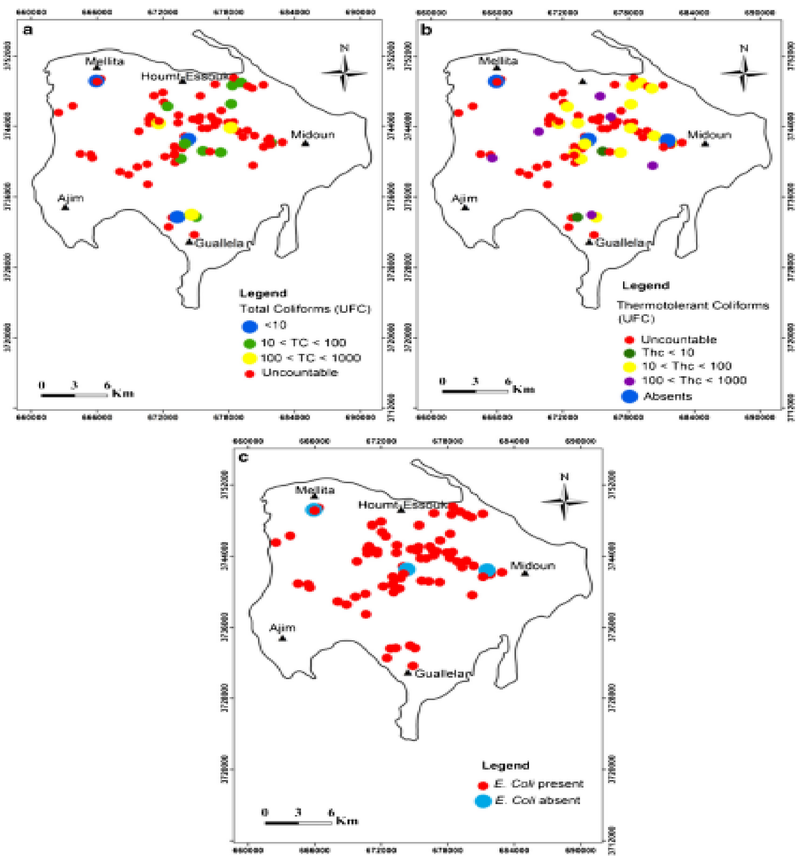


Figure 2. Spatial distribution of fecal tracers in Jerba unconfined aquifer: a) Total coliforms, b) thermotolerant coliforms, and c) Escherichia coli (Souid et al. 2017)

The origin of salinization is mainly attributed to irrigation, water recirculation and intensive pumping (Trabelsi et al. 2005). Furthermore, the water table overexploitation and the many septic tanks lead to an increase in organic pollution of groundwater.

The lack of sewage systems in the suburban areas of the island leads ultimately to the underground pollution that reaches the water table. In addition, stormwater is considered a pollution vector as it mobilizes surface pollutants into the aquifer. Abandoned dug wells and septic tanks have been identified as direct sources of contamination that contribute to increased chemical and bacteriological inputs. In addition, contaminants from seawater, especially Cl^- and Na^+, migrate from shallow coastal areas of the aquifer to larger areas due to excessive groundwater pumping. Thereby facilitating the passage of contaminants from nearshore marine origin and point-sources of pollution to different parts of the aquifer and contributing to groundwater contamination (Souidet al. 2017).

With a capacity of 50,000 m^3 of water per day and a possible expansion to 75,000 m^3, the island's drinking water needs could now be met entirely by freshwater. The same amount of highly saline water is discharged into the northern marine environment of Djerba with a salinity of about 72 mg/L. The effluents should be sunk in deep water to achieve a good dispersal effect. The effluents discharged into the coastal area are mostly polluted with suspended particulate matter in southern coast of Djerba and less on the northern coast, which could lead to anoxic conditions with anaerobic methane oxidation and sulfate-reducing bacteria. In fact, a seasonal study of methane oxidation and CO_2 reduction rates reveals that methane production was limited to sulfate-poor sediments in all seasons, while methane oxidation occurred in two ways. In summer, methane oxidation was confined to sulfate-depleted sediments and occurred at lower rates than CO_2 reduction. While in winter, net methane oxidation occurred in an interval at the base of the sulfate-bearing zone.

II.2. Water pollution

There are four operating wastewater treatment plants (TPs) in Djerba, located in Aghir-Midoun, Houmet Souk, Sidi Mehrez, and Ajim. Data were provided by the local branch of the National Office of Sanitation (ONAS: Office National de l'Assainissement, 2018) for all four treatment plants (Table 1). These stations have different levels of treatment. The level of treatment is tertiary in the TP of Aghir and secondary in the other three (Fig.3).

Table 1. Wastewater treatment plants (TPs) in Djerba, Source ONAS

TP Wastewater (ONAS 2018)	Disposal site	Treated wastewater flow (m^3/yr)	WWTP characteristics
Houmet Souk	Sea	761,060	aerated lagoon treatment, secondary treatment (rehabilitation in progress)
Sidi Mehrez	Outfall at sea	959,765	aerated lagoon treatment, secondary treatment (rehabilitation in progress)
Aghir	Sea	1,804,588	active mud treatment, tertiary treatment (maturation).
Ajim	Sea	32,940	aerated lagoon treatment, secondary treatment (in test period)

Wastewater treatment plant (WWTP) of Aghir in Midoun: active mud treatment, tertiary treatment (maturation). This region is less polluted than the western zone of the lagoon which is mainly polluted by the aquaculture farms effluents and the Guellala slaughterhouse, as well as by phosphates compiling from Gabes Gulf waters, and finally by the construction of the Roman road that connects Djerba to the Tunisian mainland.

Other discharges occur directly into the lagoon from the fishing ports of Ajim, Boughrara and Hessi Jallaba, the desalination plant of Djerba, aquaculture farms and finally landfills, especially in Aghir. The presence of other pollution sources such as sewage discharge. However, it should be noted that compliance with discharge limits will protect the already sensitized receiving environment. Fishing is conducted in shallow marine waters using small boats.

The area of Aghir is also a seafood fishing area for restaurants and tourist facilities. In addition, there is an aquaculture facility in the discharge area, located in Jorf, 18 km from the discharge point. The two poles of tourist interest are, on the one hand, the fort at the end of the peninsula, also known as "Bordj Kastil", said to have been built around 1,555, and on the other hand, the Roman ruins of Meninx. Currently, the treated wastewater is only partially reused (15% of the nominal flow). The treated effluent of the wastewater treatment plane (WWTP) is used for the irrigation of both olive trees and the treatment plant.

Figure 3. Anthropogenic activity nearby Aghir WWTP

Impact of estimated dilution rate and velocity on the shoreline: the peak discharge rate of treated effluent to the watershed is around 241.5 m^3/h. The lagoon hydrodynamic functioning the has shown that the exchange through the channel is so low almost 0.4%, that the water stagnation in the northern and southwestern zones is inevitable, and that the wind remains the only factor that activates the lagoon water internal circulation and homogenization. Obviously, the water discharges combination has led to the ecosystem deterioration (AFFI, 2019), which in its turn has led to phosphate enrichment from Gabes Gulf waters and to a decline in biodiversity and especially fisheries resources. Moreover, the surrounding area is used for fishing and shellfish collection while the nearest bathing place is located about 5 km east of the discharge area (AFFI, 2019).

II.3. Solid waste pollution

Solid Waste management (SWM) on the island is conditioned by the geographic typology of limited land area and economic activity based on tourism projects that produce large amounts of waste. Globally, tourism contributes to the production of about 35 million tons of solid waste annually (UNEP and CI, 2003). In Djerba, tourism generates 40% of the solid waste collected annually on the island (Table 2; ACR&MED, 2016).

Table 2. Global solid waste distribution (ANGed, 2017)

	Annual (tons)	%	Daily
Total solid waste	45,000	100	-
Households waste	24,000	53	0.8 kg/inhabitant/day (ACR&MED, 2016)
Hotels Solid waste	16,000	35	2.8 kg/guest/night (Ghribi, 2012)
Street sweeping	5,000	2	-

In Djerba as well there are several types of waste generated daily from different sources such as households and tourist zones that are related to changing consumption patterns. Besides, wastes may be generated by the population growth, the increasing use of new products and consumption of packaged finished products, and rapid population growth. The organic fraction is the predominant composition (63.2%), plastic waste is up to 9.4%); textile waste is estimated at about 8.7%; paper and cardboard waste is about 8.6% metals, glass and other waste are below 10% (Fig. 4; ANGed, 2019).

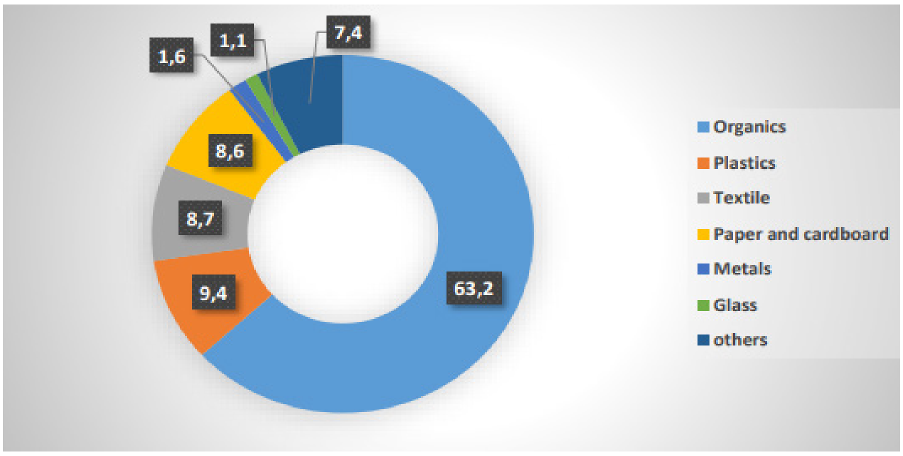


Figure 4. The municipal waste composition ANGed, 2019

It is obvious that solid waste management on islands is a troubling dilemma. In fact, the accumulation of waste should be controlled throughout the whole process from collection to transportation to disposal. On the island, solid waste collection is carried out with the same municipal engine, and the destination is the landfill. Until 2011, there was a single controlled landfill called Guellala Landfill, located on the highest point of the island. After that date, due to pressure from residents, the landfill was closed to controlled waste dumping. The only 03 transfer sites are still used today as temporary open-air storage facilities, namely:

- Houmet Souk
- Midountransfert
- Aghirtransfert

Household waste and street sweepings and hotel solid waste are disposed of at these three transfer points. Hotel solid waste dominates in the Midoun transfer point, while it is less represented than household and street waste in the Houmet Souk transfer point. In the Aghir transfer point, hotel waste is almost insignificant.

These three sites are considered as a temporary solution for the last decade (2012-2022) with exponential growth. Waste pressing and packaging are carried out at this site as a temporary solution in Aghir (Fig.5). But by 2021, the situation in this temporary storage site becomes more critical as it turns into an open-air landfill where about 200,000 tons of waste is stored in bales, which should be removed by the end of 2021.

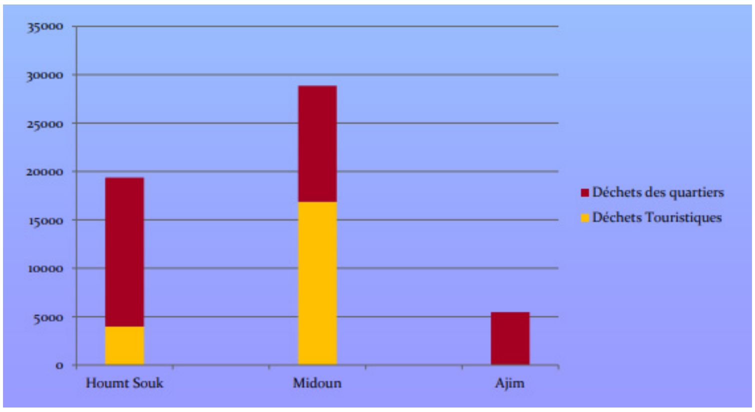


Figure 5. Amount of waste collected from three communes in Djerba (Ben Abdallah M, 2013)

II.4. Coastal pollution

In the coastal area of GuellelaAghir (Bin elWediane), specifically in the northern Bougrara lagoon and its surroundings, there is an accumulation of organic material in the sediment. This accumulation is certainly due to the joint effects of the cages in the sea placed in 1992 by the aquaculture company (AST). On the other hand, the presence of the port of Boughrara, a pure lagoon sector, or the environment enrichment with organic matter is more related to the wastewater discharges treatment plant of Aghir (Guetatet al. 2012) to this organic metal enrichment, where especially Cu and Cd enrichment was detected in the same area (Table 3, Fig. 6).1

Table 3. Comparison of trace element mean values to guideline criteria

Elements		Cr (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Cd (mg/kg)
Lagoon Boughrara	Minimum	7.5	25.4	64.4	3.8	0.8
	Maximum	20	97.7	104.1	8.9	2.1
	Mean	12.63	40.16	88.88	6.11	1.57
NOAA	ERL	81	34	150	46.7	1.2
	ERM	370	270	410	218	9.6
Toxicity classification (USEPA)	Non polluted	<25	<25	<90	<40	_
	Moderately polluted	25-75	25-50	90-200	40_60	_
	Heavily polluted	>75	>50	>200	>60	>6

Concentrations of Cr, Cu, Zn, Pb, and Cd were evaluated in a screening-level ecological risk assessment by comparing them to numerical SQGs such as ERL and ERM. Here, ERL (effects range low) is interpreted as the concentrations below which adverse effects rarely occur, and ERM (effects range median) is interpreted as the concentrations above which effects frequently occur (Long et al. 1995). Compared to the ERL-ERM SQGs, the concentrations of all elements are lower than the ERL and ERM, except for Cu in front the region of Guellela where the value (97.7mg/kg) is higher than the ERL.

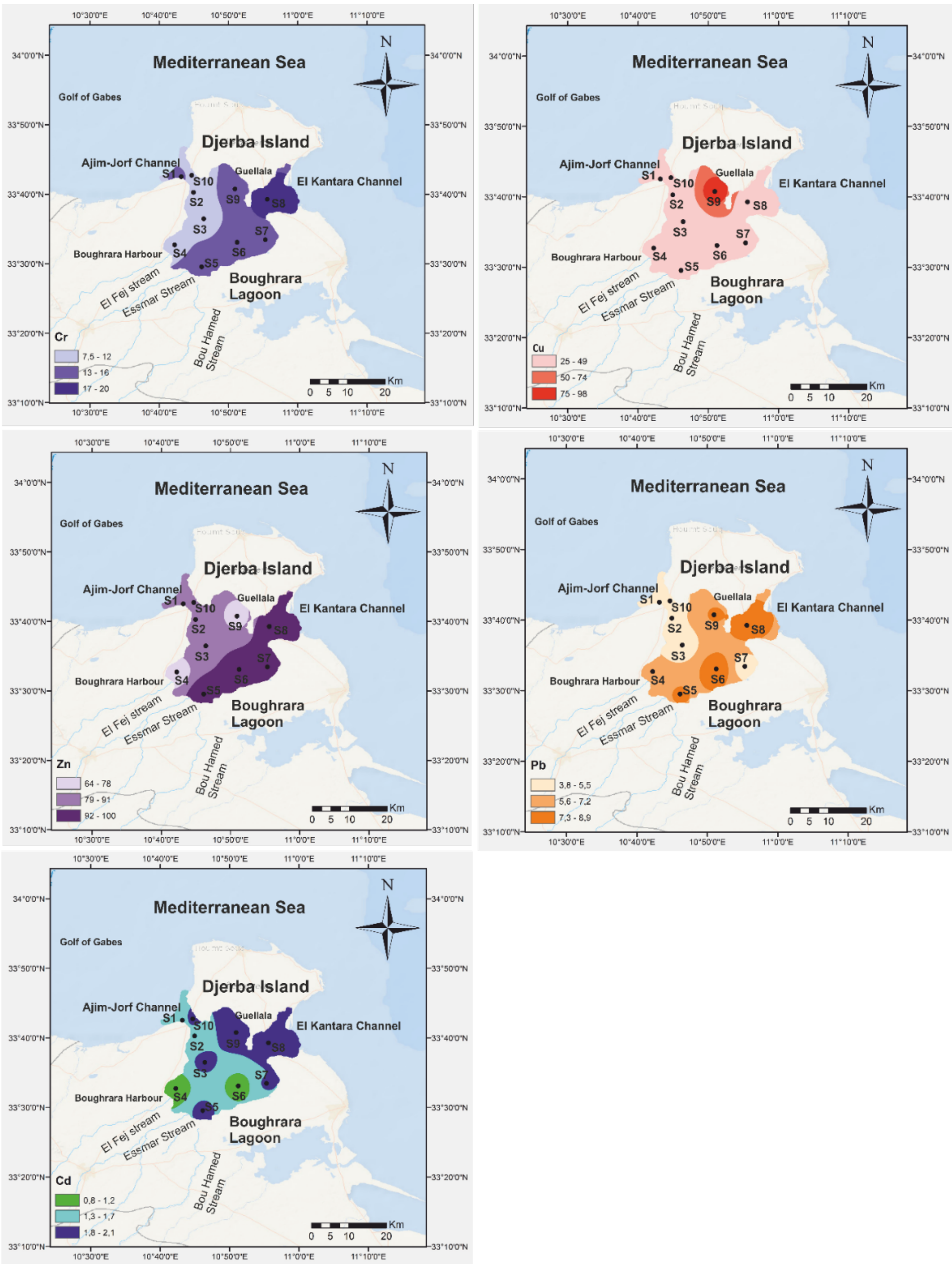


Figure 6. Trace element in southern Djerba Island (Boughrara lagoon)

According to the toxicity classification (USEPA), the mean concentrations of Cr and Pb indicate that there is no contamination in the southern coastal area of the Island. Therefore, Cd exceeds the ERL in front of Aghir landfill and the heavily polluted sediment for Cu near Guellela (97.7 mg/kg > 50).

II.5. Air pollution

The carbon emissions average value in Djerba per tourist per night was estimated at 25kg CO_2 in 2017and the total carbon emissions from tourism were estimated at 100330t CO_2 per year. The distribution of (GHG) emissions related to the corresponding activities is shown in Figure7. This reveals the hotspots in terms of carbon emissions from tourism, which should be the focus areas for the sector decarbonization.

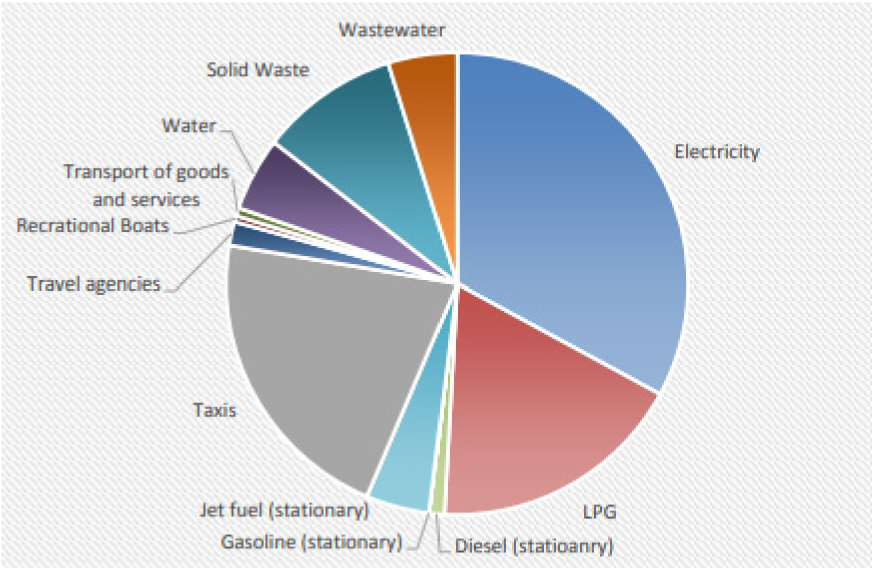


Figure 7. Contribution of tourism with Greenhouse Gas (GHG) emissions in Djerba

The sulfur dioxide regional distribution (SO_2, NO_2) on the island shows a decrease in recent years compared to other Tunisian regions, especially in the north. For all Tunisian regions, this decrease was about 60% and 40% for SO_2 and NO_2, respectively (Wood et al. 2018). The regional distributions of carbon monoxide (CO) for 2020 and 2021 also show a decrease, which is about 20% compared to the previous year (Wood et al. 2018). This decrease is related to the decrease in tourism activities in Djerba in recent years.

III. Evolution of the different types of Pollutants

III.1. Wastewater evolution

To illustrate the evolution of treated wastewater quality in the wastewater treatment plants at the island (Djerba Aghir, Djerba HoumetEsouk, Djerba Sidi Mehrez and Djerba Ajim; Fig.8),Several basic criteria such as effluent quantity, quality and composition were established.

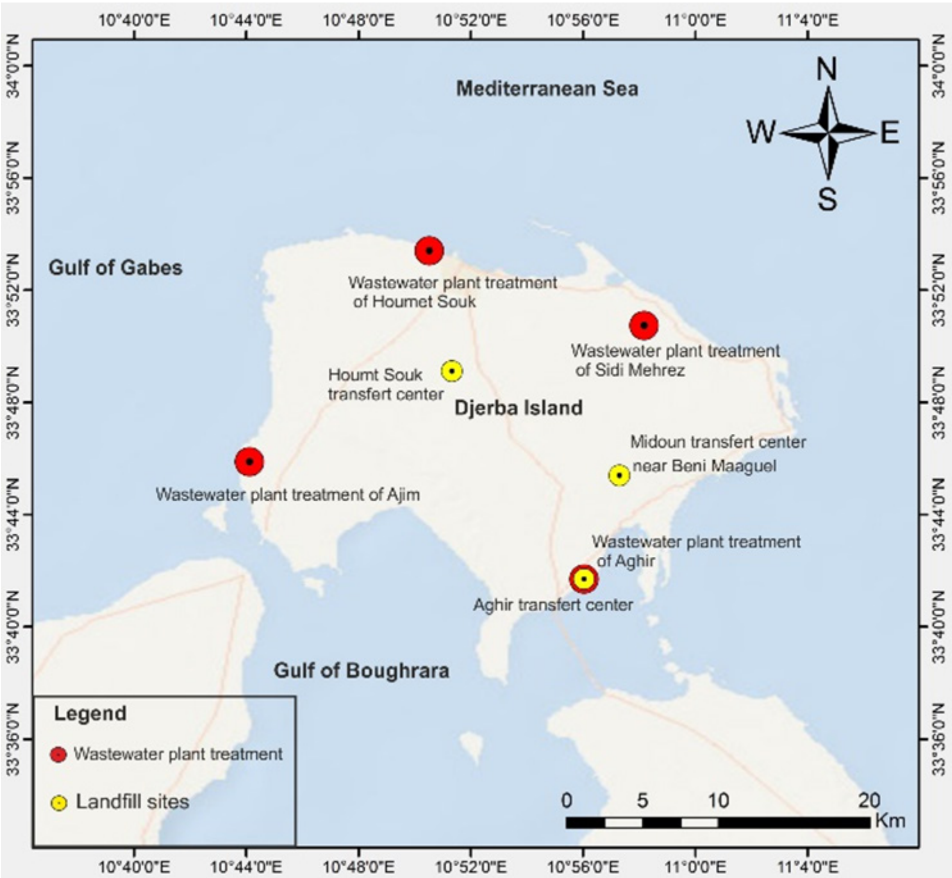


Figure 8. Principal sources of wastewater and solid waste in Djerba Island

The wastewater flows treated in Djerba Aghir water plant are higher (especially in 2017) than the one in Djerba HoumetEsouk and Djerba Sidi Mehrez water plants. It should be emphasized that the station of Djerba Agim water plant was put into operation in 2018 (Fig.9).

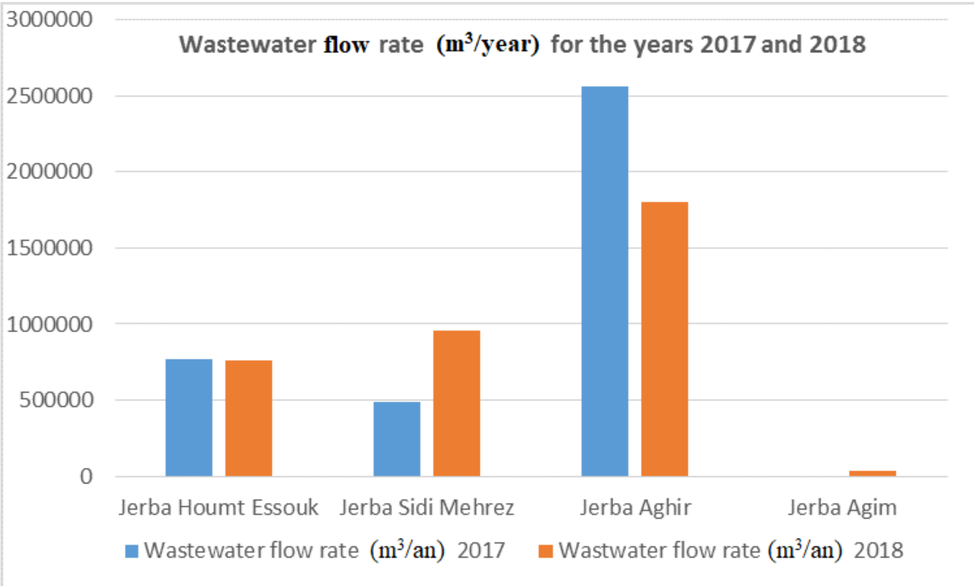


Figure 9. Wastewater in different coastal areas of Djerba Island between 2017 and 2018

The flow rate represents the volume of water that arrives to the plant per unit time. Wastewater discharges on the coast of Djerba have different compositions depending on the degree of treatment. The wastewater composition, as well as its organic load, can be used as an indicator of pollution degree, to know the different pollutants discharged and thus determine the treatment type that must be applied to each water plan. For this purpose, it is necessary to determine the main indicators.In fact, the indicators BOD, DCO SPM can be used to predict the trophic status of the receiving environment as well as organic pollution.

- BOD5 represents the amount of oxygen consumed by a sample after 5 days. It considersbiodegradable carbonaceous organic pollution.
- COD represents the amount of oxygen required to oxidize all organic matter contained in the water. SPM is the total suspended particulate matter contained in a wastewater that can be retained by centrifugation or filtration.Referring to the Tunisian standard NT 106.02 and the European Directive 91/271 regarding the concentrations of effluents from wastewater treatment plants, Both Djerba HoumetEsouk and the Djerba Sidi Mehrez wastewater treatment plants have exceeded the thresholds of the standard NT 106.02 and the European Directive 91-271 (Table 4).

Table 4. Wastewater discharge standards

Standards	Biological Oxygen Demand	Chemical Oxygen Demand	Suspended particulate matter
Tunisian standard NT 106.02 (hydraulic environment)	30 mg O_2/L	90 mg/L	30 mg/L
European Directive 91-271	25 mg/L	125 mg/L	35 mg/L

Regarding the water quality, expressed by the indicators of water quality concentrations of BOD5, COD and SPM, it reveals that both Djerba HoumetEsouk and Djerba Sidi Mehrez plants have proven to have the highest concentrations and are as well the most conspicuous for BOD5 and COD(Figs. 10,11, 12).Even though Djerba Aghir plant has lower values, yet it records the highest flow. This is due to the tertiary treatment process in this station. The plants of HoumetEsouk and Sidi Mehrez, on the other hand, show a very high organic load, which is due to the intensive tourist activity in the region of HoumetEsouk and Sidi Mehrez (Midoun), as well as to the type of secondary wastewater treatment in these treatment plants.

Suspended particulate matter indicates an inadequate treatment of organic matter in the wastewater. In Aghir wastewater treatment plant, although the values are within the standards, other indicators such as fecal coliform bacteria and fecal streptococci may exceed the standards. These parameters are exacerbated by the very low flow velocity and low water level in this part of Boughrara Lagoon (AFFI, 2019).

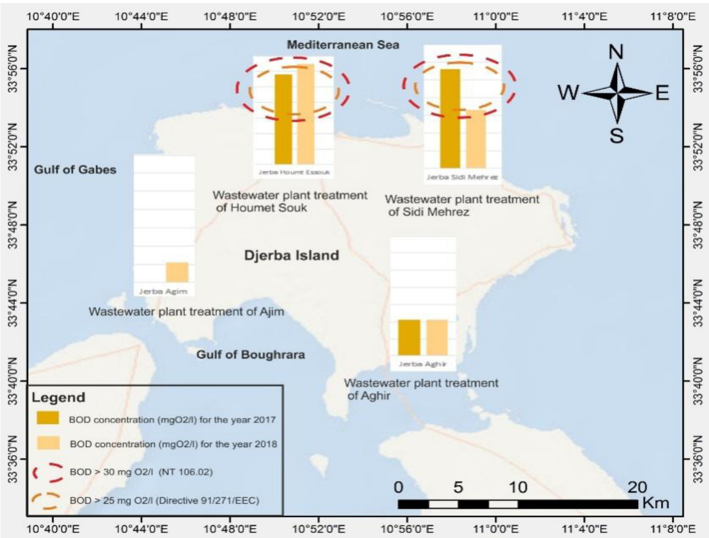


Figure 10. Biological Oxygen Demand (BOD) in wastewater discharge water plant in coastal area

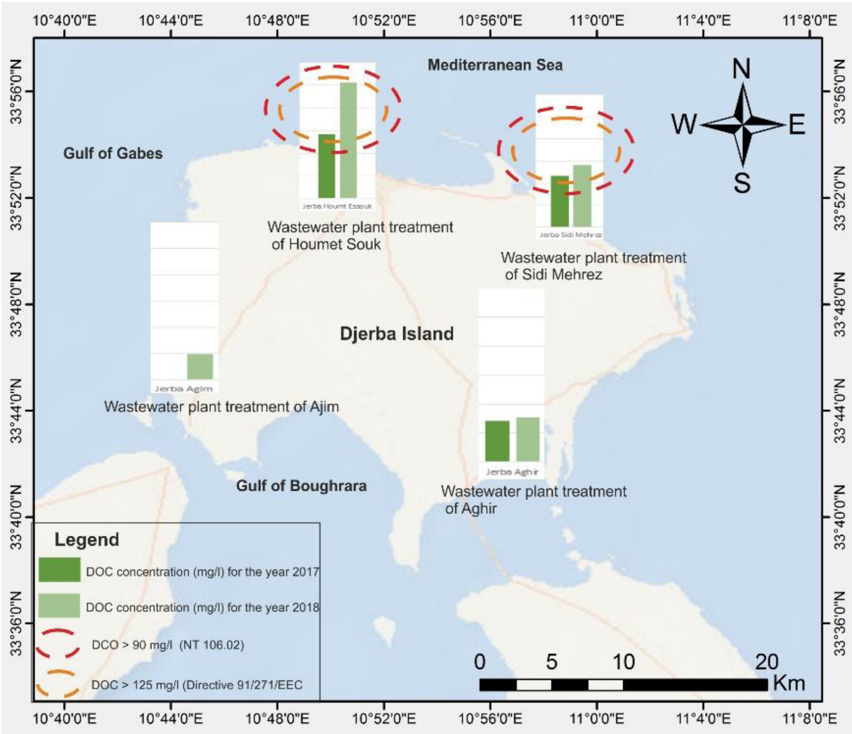


Figure 11. Chemical Oxygen Demand in wastewater discharge water plant in coastal area

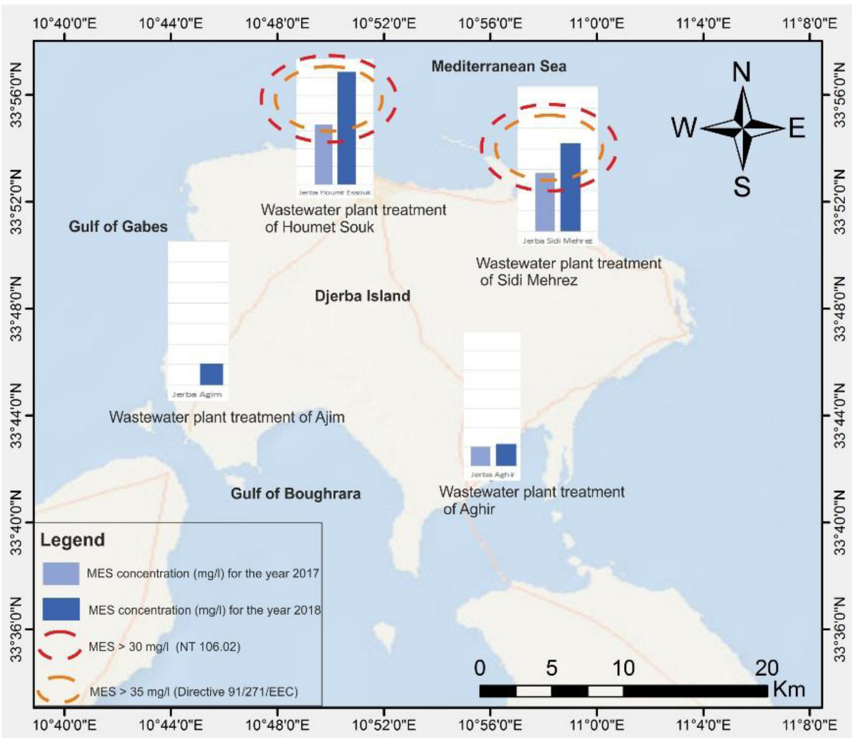


Figure 12. Suspended particulate Matter (SPM) in wastewater discharge water plant in coastalarea

In Djerba, recent years' trend in wastewater treatment plants shows an increase in organic pollution indicators. The suspended particulate matter increases in some areas treated with water. This may lead as a result to the contaminated SPM deposition in the bottom water, especially in the Bin El Wediane area, where the water column is very weak, and the bottom is irregular. On the other hand, flooding, dredging and shipping can lead to a significant sediment remobilization, which is accompanied by an increase in the contaminants' concentration in the water phase, especially since these particles are very fine.

These aspects show the fraction complexity role, the SPM, and sediment sinks, transporters, and sources of particle-bound substances. The SPM is therefore of critical importance in assessing surface water contamination in nearshore drainage areas.

As for the estimated flow of treated effluent over the years, the annual evolution shows homogeneity in each treatment plant except for a very high flow that can be estimated to be double or triple in Aghir station compared to Sidi Mehrez and Houmet Souk stations (Fig.13).

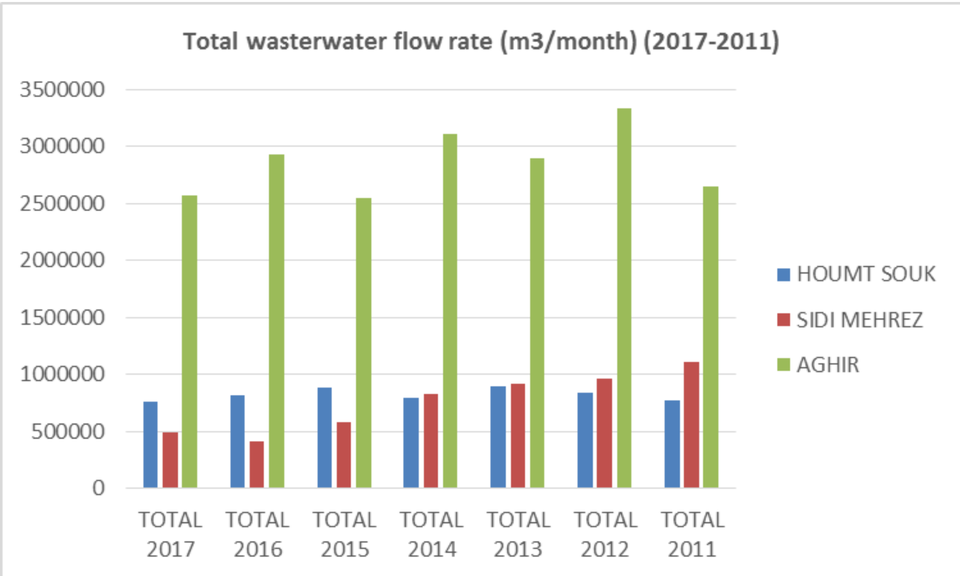


Figure 13. Annual wastewater in Houmet Souk, Sidi Mehrez and Aghir

The indicators show that the water treatment quality in Djerba wastewater treatment plants is as crucial as the overtreated quantity. In this case, tertiary water treatment is required to achieve the performance targets for the three parameters BOD, DCO, SPM and/or have a failure high probability.

To comply with the values indicated in the new standards, the first step is to increase the wastewater treatment plants' capacity. Therefore, the first rehabilitation works, which consist in repairing or replacing the wastewater treatment plants equipment, are necessary, or decide to carry out tertiary treatment in all plants. In the tertiary Aghir plant, this treatment is achieved by ozonation, UV treatment or sand filtration.

Tertiary treatment includes one or more of the following:

- Disinfection by chlorine or ozone (to eliminate pathogens).
- Neutralization of dissolved metals.

The presence of other pollution sources, such as treated wastewater discharges, with a high organic pollutants content (P, N) can lead to an increase in eutrophication. In this case, there is an increased environmental quality deterioration, especially in terms of water turbidity, biodiversity and mortality of less stress-tolerant species, and shellfish species contamination in the discharge vicinity. However, it should be noted that compliance with the discharge limits will protect the already sensitive receiving environment.

III.2. Solid waste evolution

Solid waste management represents a major problem in Djerba, which is the main tourist destination in Tunisia, affecting the production of solid waste. To ensure sustainable and effective waste management on this tourist island, an appropriate waste management strategy should be adopted.

Over the years, a significant increase in the amount of solid waste was recorded in the municipalities of Midoun and Houmet Souk, which had the highest values in 2017. The increase in solid waste on the island has increased. It also requires an integrated waste management system implementation. With the closure of the Guellala landfill in 2012, the situation became more complicated. In fact, to alleviate the waste disposal problem, a consolidation unit and a temporary landfill were established in Aghir in 2015. This currently serves the three municipalities through three transfer stations and temporarily receives solid waste until a comprehensive solution is found. However, there is still an increase in solid waste on the island (Fig.14), which is temporarily consolidated in a single location. These have become dangerous places of odor nuisance and the crushing of the packaging bags of these wastes promotes the spread of leachate.

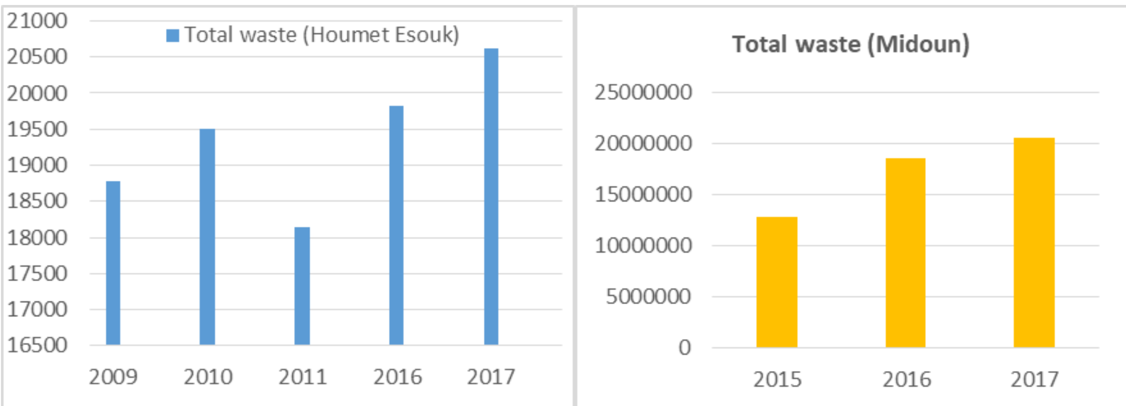
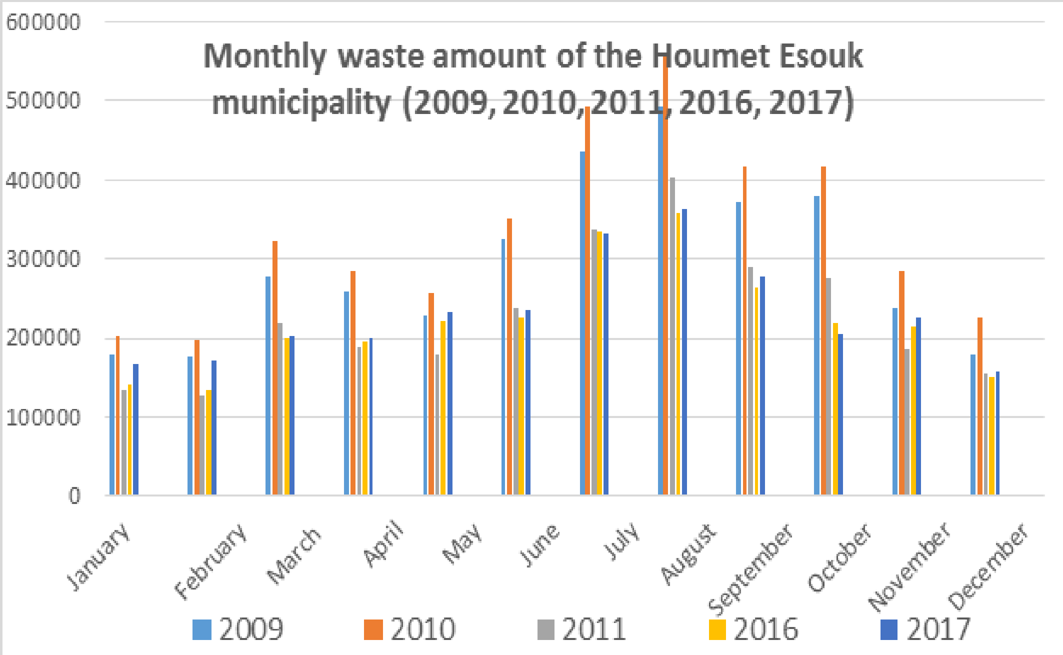


Figure 14. Annual solid waste evolution in transfer center of Djerba Island in recent years

The monthly solid waste evolution is clearly illustrated in Figure 15 shows a maximum accumulation in the summer season, specifically in July and August 2009-2010, when most tourists arrived in Djerba Island and Tunisia in recent decades. In this period there is a generation of large quantities of waste that causes far-reaching environmental, social, and economic impacts on the local communities.

The increase of solid waste should be controlled by considering the peculiarities of this place, its climatic conditions favorable to tourism and its vulnerability, as well as the lack of waste disposal areas. In addition to the available infrastructure, seasonal fluctuation of the population, consumption habits of local communities, all make it environmentally friendly and socially acceptable.

The solid waste storage in an open landfill with poorly preserved or even shredded packaging results in soil, air, and water pollution, which is a breeding ground for biological contamination by flies, rodents, and insects. These biological vectors can cause diseases typical of this type of environment, such as diarrhea, cholera, dysentery, various types of infections, food poisoning, and leptospirosis. However, the island example shows, the extremely low levels of contaminants and the lack of information on exposure limit the quality of detection. Residents living within 2 km of the landfill are most likely to be affected by the landfill's negative impact. Therefore, it is important to determine the number of families living within this radius to further quantify the health impacts of the landfill.



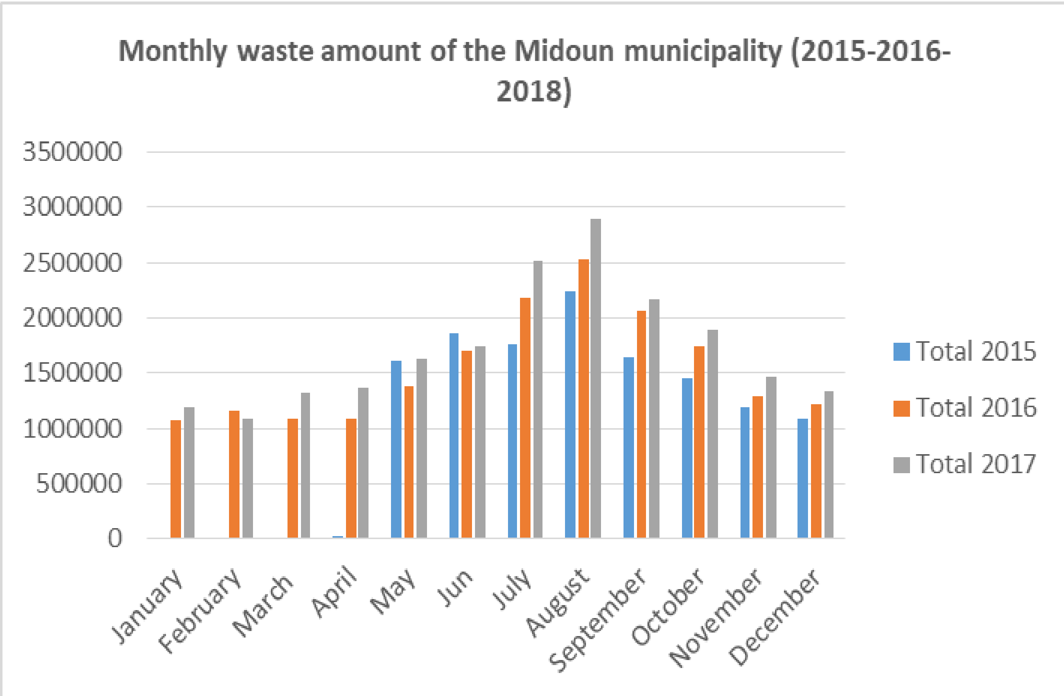


Figure 15. Monthly waste evolution in the transfer center of Djerba Island in recent years

III.3. Air pollution evolution

The concentration of sulfur dioxide (SO_2) decreased in Djerba (Table 5). In fact, this decrease near the ground depends mainly on various environmental and meteorological factors, for example, the general circulation of the atmosphere, which directly affects the concentration of air pollutants. Local meteorological parameters such as temperatures, the occurrence of thunderstorms with high air temperatures, or the occurrence of forest fires can affect the stability of the atmosphere and, in the case of high atmospheric pressure, affect these concentrations.

Table 5. Surface air pollutants (SO_2, NO_2, O_3 and CO in $\mu g/m^3$) in Djerba

	SO_2	NO_2	O_3	CO
2019	1.50	0.95	75.93	143.26
2020	2.12	1.04	81.84	143.90
2021	1.17	0.88	77.52	138.52

We also found that nitrogen dioxide concentration (NO_2) and carbon monoxide (CO) decreased slightly in 2021. Carbon monoxide (CO) was detected in most Tunisian regions. O_3 levels are stable in recent years and comparable in most Tunisian regions, especially in southern Tunisia. Air quality seems to have improved in almost all regions.

IV. Identification of coastal hotspots according to their vulnerability

IV.1. Water pollution

It is important to note that all wastewater discharges exceed Tunisian standards (N T 106-002) for phosphorus, DOC, DBO and suspended solids. The areas affected by salinization (Fig.16), located in the northern part of the island, may result in the intrusion of saline seawater. In addition, the overuse of septic tanks and the use of abandoned wells as landfills for organic waste led to the contamination of groundwater (Fig.16).

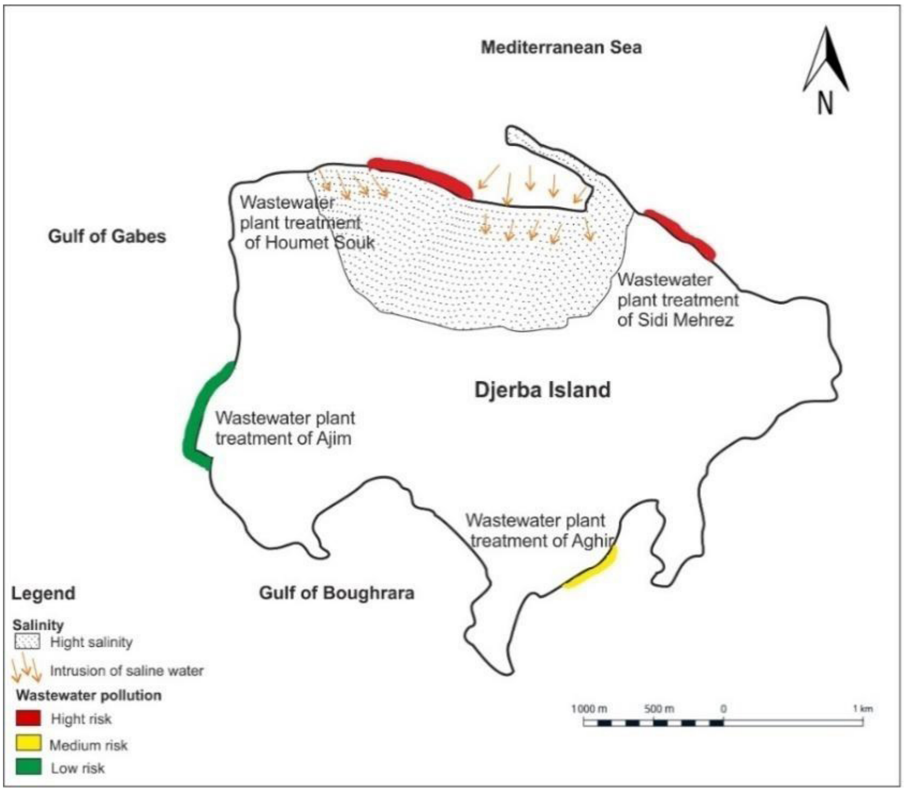


Figure 16. Coastal hotspots according to their vulnerability to wastewater and salinization

The desalination plant discharges in the northern part of Djerba Midoun, consisting of brine and other products used in pre-treatment. The hypersaline water seeping in the coastal area with a salinity of about 72 mg/L, has an important impact on the environment. The pollutant discharges from aquaculture farms on the shores of the lagoon contribute to a large extent to the organic pollution of the water (Sud Aquaculture Tunisia since 2006 and Tunipêche since 2005). Liquid and solid effluents from industries in the Gulf of Gabes, both polluted with phosphogypsum (600 to 650 t/h) and other pollutants (fluorine and P_2O_5) coming from the Ajim Channel. Pollution from the fishing ports of Jorf, Ajim, Boughrara and Hassi Jallaba, located on the shores of the lagoon. Discharge of raw sewage from the slaughterhouse of Guellala (since 2008, a decanter has been installed for pre-treatment).

IV.2. Organic pollution

The amount of compressed waste was about 84,670 tons by 2017. In 2021, more than 200,000 tons of solid waste will be disposed of (Fig.17).

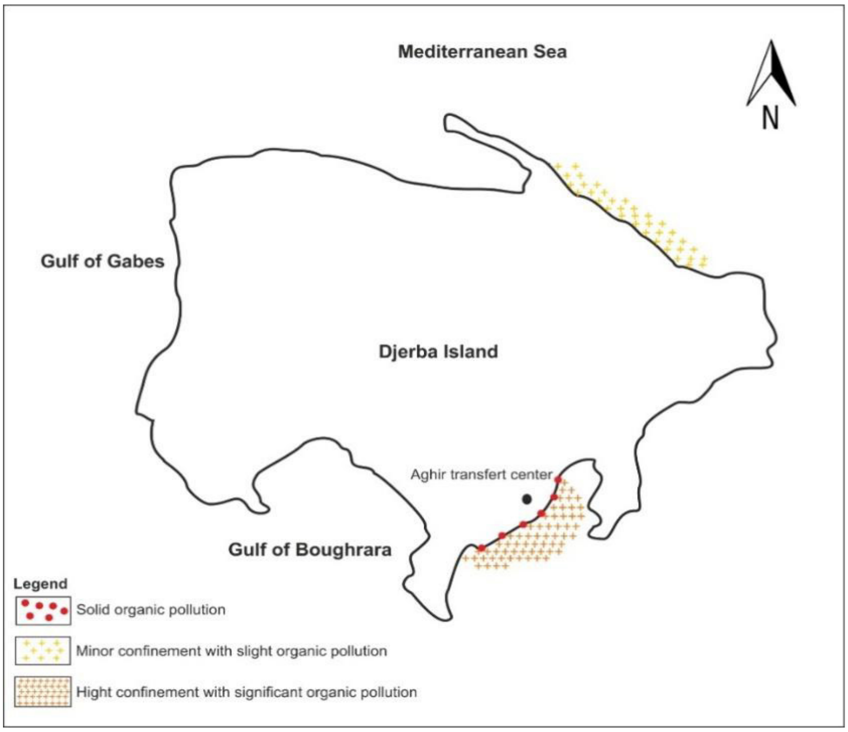


Figure 17. Coastal hotspots according to their vulnerability to organic solid waste effects

The sewage sludge storage is currently carried out in an anarchic manner in the wastewater plant. The studies of the Master Plan for the management of sewage sludge from WWTPs, carried out in 2015, recommended the construction of covered sheds at the WWTP site level. In the meantime, it is also estimated that sludge recovery channel establishment is possible through its reuse in agriculture and in cement factories as fuel, and of disposal routes through environmentally safe burial either at the level of individual landfills to be built or at the level of existing solid waste landfills.

Uncontrolled landfills have a significant impact on the health of local communities. Once waste is deposited in a landfill, it undergoes a series of biogeochemical processes. Residents living near landfills have been proven to be exposed to chemical mixtures from the resulting leachate or landfill gas, which can pose a significant health risk.

This situation continues to this day, with more than 200000 tons of bale waste disposed of on the beach, creating new environmental problems on the island, such as: Leachate entering the sea; torn bales and scattered waste in the environment; invasion of animals, birds, and insects...*etc.*

V. Impact of coastal/maritime tourism on local environment

The interaction between environmental quality and tourism should be analyzed mainly in its temporal course. As the island's tourism sector has undergone significant changes in the last decade due to the popular revolution in late 2010- early 2011 and two terrorist attacks in 2015 perpetrated in Tunis, the capital of Tunisia, and Sousse, two major Tunisian tourism destinations (Wood*et al.* 2018). As shown in Figure 18, the number of tourist overnight stays in recent years is significantly lower in 2016-2017 than between 2008 and 2010. The ecosystem approached in this case shows quite different levels of service over time. The goal is to assess the impact of tourism on the natural resources use. The impact of this industry on the ecosystem is realized through the different ecosystem services that pose a real threat to the environment.

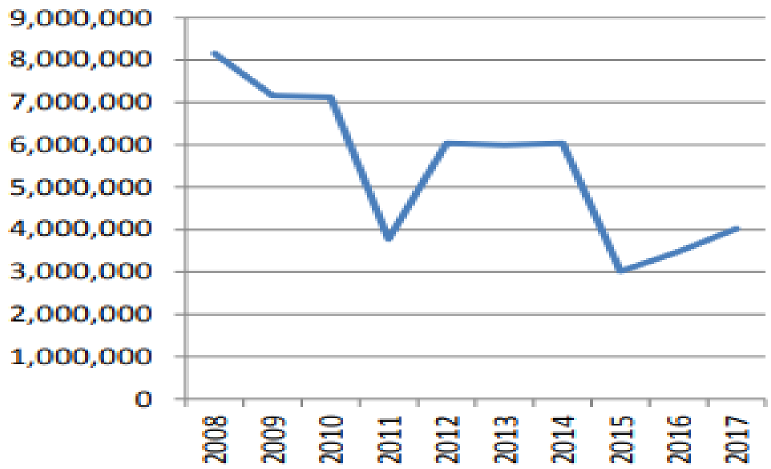


Figure 18. Evolution of tourist nights in Djerba between 2008 and 2017 (ONTT, Wood et al. 2018)

V.1. Wastewater

The wastewater plants of Aghir and Sidi Mehrez cover the tourism zone and it has been proven that tourist nights are the main reason for wastewater generation at these plants (Wood *et al.* 2018), as shown in Figure 19. Nevertheless, a small number of households in the nearby tourism zone (mainly in Aghir) are connected to these plants. In addition, there is no rainwater collection system in Djerba, so the wastewater data includes runoff. It is assumed that this should not have a significant impact on the current assessment given the low annual water consumption (AFFI, 2019). It is possible to estimate the proportion of treated wastewater attributable to residences by examining low tourism months, as discussed in Table 6. Indeed, during December and January, tourist overnight stays are not the most important parameter for wastewater production.

Based on the above assumptions, tourism was responsible for 57% of wastewater production in 2017, with an average production per tourist night of 690 L. In terms of the whole island, these figures should be considered together with the fact that the connection rate to the public sewage network in Djerba is very low. According to data in previous assessments, the connection rate in Djerba was 33% (ANPE, 2016).

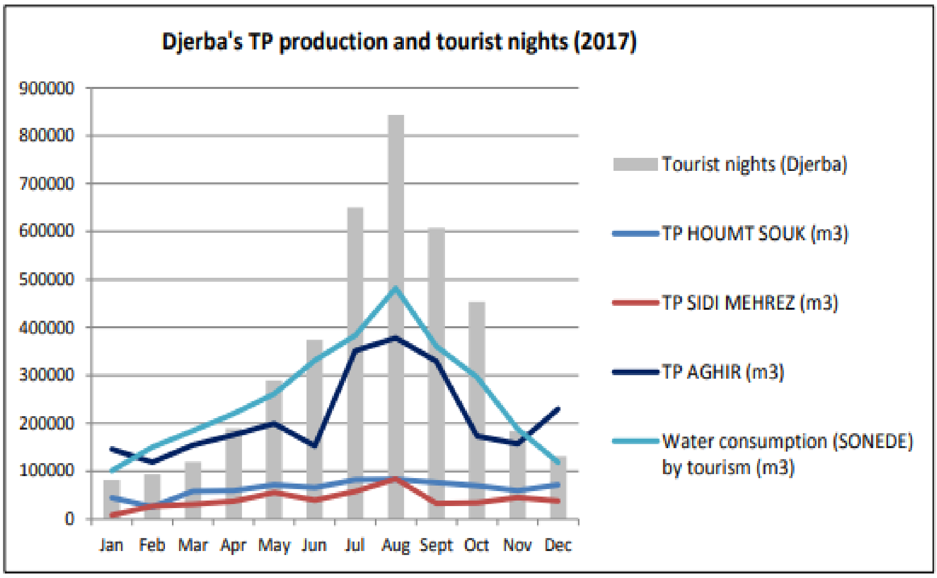


Figure 19. Djerba treatment plants production compared to tourist nights (ONAS, SONEDE, ONTT, Wood et al. 2018)

Table 6. Water consumption by tourism and wastewater production.

	2017	2016	2015	2014	2013	2012
Water consumption by tourism (m^3)	3,075,208	2,695,771	2,927,047	4,166,110	4,225,244	4,091,852
Wastewater production: TPs of Aghir and Sidi Mehrez* (m^3)	3,051,923	3,348,652	3,121,775	3,,107,977	3,818,766	4,292,919
Water reuse (m^3)	548,761	493,692	620,987	855,879	1,153,724	1,091,232
Ratio of water reuse to tourism's water consumption	17.84%	18.31%	21.22%	20.54%	27.31%	26.67%

It has been revealed that the average national connection rate in urban areas is 90%, with 57% of the total population of Tunisia having access to the sewage network (ONAS official statistics). While in Djerba, the connection rate is 100% in tourist areas, but much lower in purely residential areas. Only 50% of homes are connected (more in the cities, less outside the cities) because local people cannot afford the connection costs.

V.2. Solid waste

Total solid waste dominates in HoumetEssouk, but waste from hotels dominates in Midoun. Tourism has a significant impact on the solid waste generation on the Island, as the rate of waste generated by tourism is almost 3.5 times higher than the rate of local waste in Djerba (2.8 kg/night versus 0.8 kg/inhabitant/day) (Figs. 20, 21). This situation seems quite worrying because the existing infrastructure is not able to handle all the waste generated due both to the limited availability of land for disposal and financial resources (Chen et al. 2005). In addition, seasonal tourism produces excessive amounts of waste during periods of high tourist activity, often exceeding the island's capacity. The enormous tourist activities in Midoun and its dangerous impact on the environment in this region. It seems to aggravate the problem of pollution of the temporary garbage dump of Aghir.

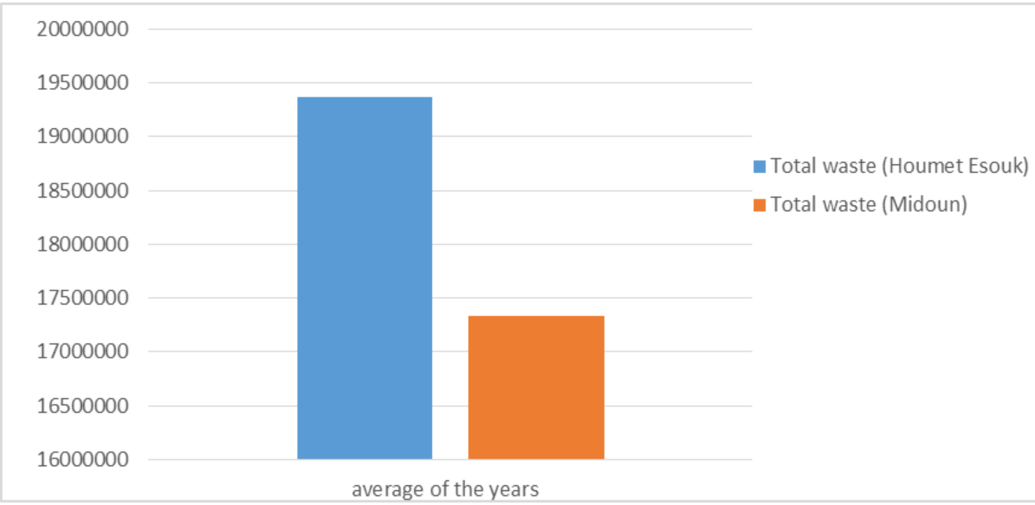


Figure 20. Average solid waste of HoumetEsouk and Midoun municipality (2009-2017)

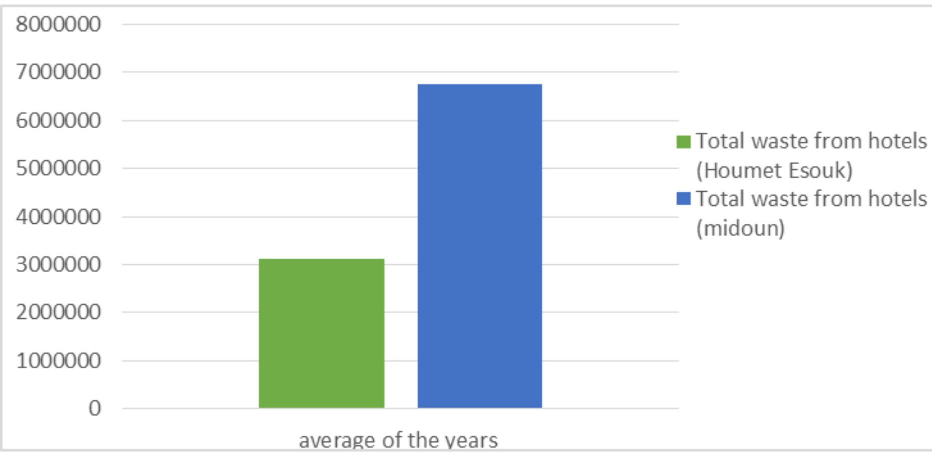


Figure 21. Average Hotels solid waste of Houmet Souk and Midoun municipality (2009-2017)

these three summer months. In fact, it proved to highly affect the tourist experience and the host community. Moreover, tourism influences the consumption behavior of local people by exposing them to new ideas and products (Nair and Jayakumar, 2008), which leads to some changes in local consumption and waste disposal. In this context, the only landfill suitable for controlled solid waste dumping was closed in 2012 after social protests environmental degradation and dumping in some regions such as Djerba, Kerkennah, *etc.* After the closure of the Guellala landfill, in May 2012, municipal waste from households and hotels was transferredto an old non-sanitary landfill and dumped in the air. In 2015, a temporary solution was introduced for the pressing and packaging of waste at the old landfill of El Kantara.

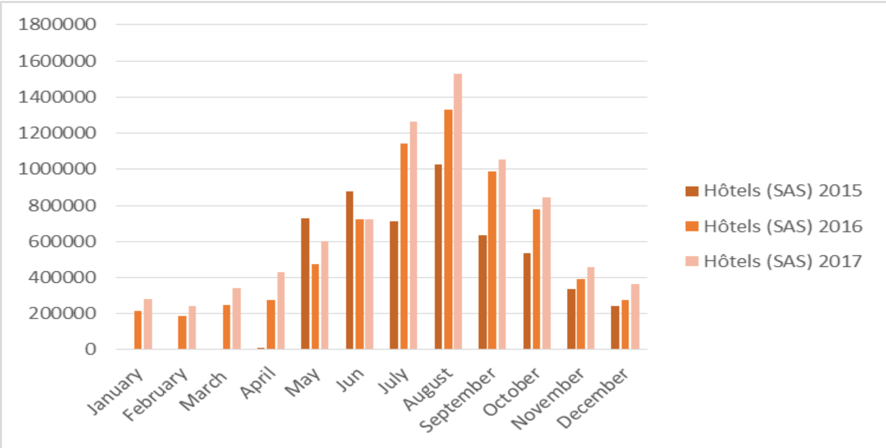


Figure 22. Monthly hotels solid waste in Midoun municipality for the years 2015, 2016 and 2017

VI. Policies and strategies for pollution mitigation

Human activity is very important in the coastal environment, especially at the island level. Therefore, good, harmonious management is required, which responds efficiently to sustainable development. Awareness and the fight against pollution have become an important priority on the island. In fact, several actors are involved in the fight against this pollution, whose main objectives are the sanitation of domestic wastewater and waste management. The prevention and elimination of pollution requires a global mobilization and, above all, a perfect coordination between these actors to achieve common objectives. Many of them are actively engaged in good environmental management.

VI.1. Water resources and quality

Water quality is the most important challenge for human needs and health in Djerba because the groundwater suffers from salinization due to the groundwater overexploitation and the lost water pollution. For this reason, SONED strengthens the water resources of the Island through a desalination plant. The Djerba seawater desalination plant was officially commissioned in May 2018. With a treatment capacity of 50,000 cubic meters of seawater per day (expandable to 100000 cubic meters per day in a second stage), the plant was built to meet the island's water needs and reduce the water deficit. The impact on the environment of the hypersaline water deposited at the level of the coastal sound Djerba Midoun has not been well insured yet.

According to ONAS, to improve the quality of treated wastewater to meet the standards of rejection (reduction of suspended particulate matter, DBO, DCO...) and increase the potential for reuse of water on the island, the treatment plants of Sidi Mehrez and Houmet Souk will be upgraded to apply the tertiary treatment technique. In this context, the treatment plant of Houmet Souk will also be rehabilitated along with the pumping stations and the treatment plant of Djerba.

In addition to the four wastewater treatment plants operated by the Office National de l'Assainissement (ONAS), there are several hotels that treat their own wastewater, but this data is not collected. Yet, two five-star hotels and two four-star hotels reported having private treatment plants on their premises. ONAS data do not distinguish between different users of the wastewater system, so there is no readily available data on tourism related wastewater generation or even stormwater (AFFI, 2019; Wood et al. 2018).

VI.2. Solid Waste and marine litter

Solid waste disposal from tourism operations units is managed as urban waste, without appropriate practices. Thus, the collection is ensured by the same municipal locomotive and the destination is the temporary storage in the landfill of Aghir.

In Djerba, most of the coasts and beaches are affected by plastic pollution. A collaboration between the Ministry of Tourism and the Ministry of Environment has led to a pilot project called “Djerba without single-use plastic products”, recently launched to improve the environmental situation and protect the coastline.

There is a lack of integrated municipal solid waste management. Hotels need to find alternative ways to dispose of organic waste and separate it from other solid waste. Due to the scarcity of companies that collect compostable materials separately from other solid waste, most hotels do not separate organic waste. Only three companies collect recyclables in Djerba, all of which are exported to other cities. In addition, one local company collects grease residues from hotel dishwashers for separate treatment. So far, there is no solution for garden waste, hazardous waste (batteries, *etc.*) and construction waste.

As for plastic, paper cardboard and cooking oils recovery, some hotels have agreements with Tunisian recycling companies. The plastics are sorted at source in special containers and recycled by recycling companies outside Djerba. It should be noted that plastic waste is also recovered to be sold to a recycling company ECO-lef. Using cooking oils are apparently systematically recovered for recycling by the Eco Oleo Company. The company uses these used oils to produce biofuel. In some hotels in Djerba, there is a composting system for green waste. This compost is destined for the hotel’s garden. It should be noted that this hotel has a large area behind the hotel (ACR&MED, 2010).

VII. Maritime Spatial Planning

In the North African coastal zone of Mediterranean countries, the ecosystem services are more and more affected by anthropogenic pressures, which are increasingly promoted to prove the important place of the ecosystem and overestimate the benefits derived from natural environmental resources (Costanza et al. 1997). Ecosystem services can guide decision support to local and national authorities on a range of potential benefits that can promote different sectors in the region, especially tourism. The maritime environment is a heterogeneous space with free access and shared use that is not limited to a single level. Several users are involved in the use and exploitation of this space, competing in different types of activities. Therefore, a public process is required to coordinate an approach to the use of goods and services in marine areas within a defined spatial-temporal action framework.

Marine spatial planning (MSP) is an organizational process that is fundamental in an island area such as Djerba, where all activities are linked to the sea (Fig. 23). Considering the environmental component of the island, this suffers from a crisis in the management of solid waste, which can be worsening from one moment to another. On the other hand, the sewage problem along with the water quality deterioration affects the coastal environment due to port activities. Djerba Island is located between the activities of transport, fishing, and recreational boating. It is, therefore, a better organization of:

- Settlements
- Anthropic activities
- Infrastructure

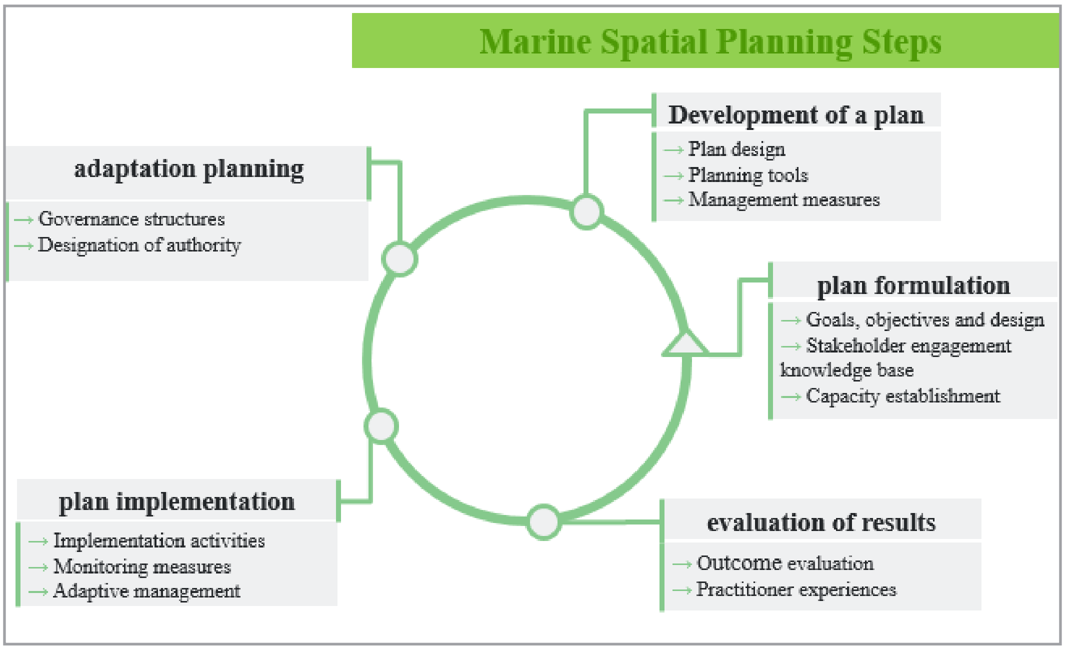


Figure 23. General steps of Marine Spatial Planning (MSP)

In this context, the establishment of maritime spatial planning and its effectiveness is ensured by reducing conflicts, encouraging investment, and promoting tourist activity by protecting the environment. Maritime spatial planning for tourism is considered a particularly important development lever for countries with long coastlines and numerous islands, according to Tsilimigkas and Rempis(2021). Diving tourism is a component of marine tourism and a steadily growing activity in recent decades. It is generally considered as an environmentally friendly activity that brings important socioeconomic benefits to local societies.

To adopt maritime spatial planning in the case of Djerba Island, it is necessary to test some functional examples of fisheries integration in MSP in all phases of maritime spatial planning. An example of MSP management is fishing (Fig. 24).

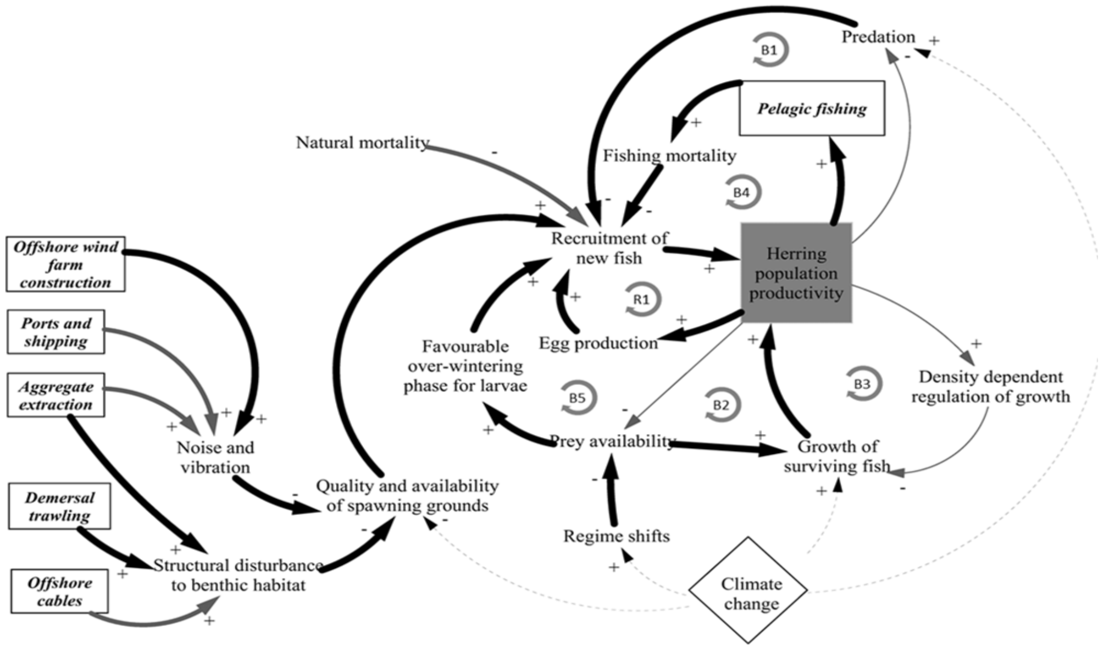


Figure 24. Marine Spatial Planning and fishing (MSP, Tunis, 2019)

Marine Spatial Planning and fishing require:

1) Increase the integration of the environmental dimension in planning.

2) Integrate spatial representation and zoning of aquaculture areas near fishing areas

3) Feed and use databases, online information exchange, bringing together the different sources of information currently available on the web.

4) Establish guidelines for the consideration of biodiversity in environmental impact studies and strategic environmental assessments of marine and coastal areas.

5) Apply the ecosystem approach in the implementation of integrated marine and coastal management. Besides, apply it to the design, establishment, and management of marine protected areas, as well as to the identification of ecologically or biologically significant marine areas, and to other area-based management activities.

6) Monitor discharges from the mainland, to ensure rational management of various types of discharges as well as better management of natural resources.

7) Update site selection for port facilities, beach fills, and siting of coastal industries.

However, the lack of appropriate data and the need for inventory, project development, negotiation and implementation data and surveys reveal a great complexity.

VIII. Conclusions

It has been well demonstrated that generally wastewater from the tourist zone is the main discharge into the marine waters, with excessive exceedance of wastewater quality parameters in the northern parts of the island. This has led to the coastal zone confinement and to bathing waters degradation.Besides, water salinization affects a large part of northern Djerba, where the urban and tourist area is extensively populated, thereis also evidence of groundwater contamination and seawater intrusion. All these problems require better management of this coastal area through good maritime spatial planning that should meet the blue economy requirements. Yet, the priority is to promote the authorities' understanding of the need for integrated waste management on the island. This has to be done in order to be able not only to introduce best practices in the waste management system development, but also to support the local decision-makers in managing municipal and hotel waste more effectively while complying with the Tunisian national waste management strategy.

IX.References

ANPE, 2016. Etude sur la gestion durable des systèmes insulaires de la Tunisie. Agence Nationale pour la Protection de l' Environment, Rebublique Tunisienne.

AFFI, 2019. Arab financing facility for infrastructure; drafting and awarding of ppp contracts in the sanitation sector in Tunisia and complementary environmental study - final report, 419.

Ben Abdallah M., 2013. Pilot experience in organic waste composting, Djerba – Tunisia. ISWA World Congress, 7-11 in Vienna, from: https://www.resource-recovery.net/en/pilot-experience-organic-waste-composting

Chen M.C., Ruijs A., Wesseler J., 2005. Solid Waste Management on Small Islands: The Case of Green Island, Taiwan. Resources, Conservation and Recycling, 45: 31-47.

Costanza R., d'Arge R., De Groot R., Farber S., Grasso M., Hannon B.,Van Den Belt M., 1997. The value of the world's ecosystem services and natural capital. Nature, 387: 253-260.

Guetat F., Sellem F., Akrout F., Brahim M., Atoui A., Ben Romdhane M.S., Daly Yahia M.N., 2012. Etat environnemental de la lagune de Boughrara et ses alentours deux ans après les travaux d'aménagement et d'élargissement du pont d'el Kantara. Bulletin de l'Institut National des Sciences et Technologies de la Mer de Salammbô Tunisia, 39:149-160

Long E.R., MacDonald D.D., SmithS., Calder F., 1995. Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. Environmental Management, 19: 81-97.

Nair Shibu K., Jayakumar C., 2008.A Handbook for Waste Management in Rural Tourism Areas – A Zero Waste Approach. Archana: UNDP India.

Souid F., Agoubi B., Kharroubi A., 2017. "Assessing the Groundwater Pollution Problem by Nitrate and Fecal Bacteria: Case of Djerba Unconfined Aquifer (Southeast Tunisia)," in Water and Land Security in Drylands: Response to Climate Change. In:Ouessar M., Gabriels D., Tsunekawa A., Evett S., Cham: Springer International Publishing, 87-96.

United Nations Environment Program and Conservation International – UNEP and CI, 2003. Tourism and Biodiversity: Mapping Tourism's Global Footprint. www.unep.org/PDF/Tourism_and_biodiversity_report.pdf.

Wood M.E., Fotiadou S., Jarrar Z., Daouda M., 2018. Tourism and Environmental Health in a Changing Climate. Report, GIZ, German Development Cooperation Agency, Harvard T.H. Chan School of Public Health. 103.

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