

Climate Change and Morphological Stability

Djerba Scale, Tunisia





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

Climate Change and Morphological Stability

Djerba scale, Tunisia



Union for the Mediterranean
Union pour la Méditerranée
الاتحاد من أجل المتوسط



CPMR
CRPM



OVERVIEW

The present document was produced in the framework of **Co-Evolve-4BG** 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 Program (Grant Agreement A_B.4.4_0075).

This document constitutes the **Deliverable 3.1.2.7** (Climate Change and Morphological Stability –Djerba scale, Tunisia) of the **Activity 3.1.2** (Threats and Enabling factors at local scale: Pilot Areas analysis) under the **Output 3.1** (Integrated analysis of Threats and Enabling Factors for sustainable tourism at MED scale) of the project.

REVIEW

Contributors

Mahmoud MOUSSA, PhD

📍 National School of engineers of Tunis

Rafik BEN CHARRADA, Engineer

📍 Engineering of the Hydraulics of Equipment and the Environment, Tunisia

Saber AMIRA, Engineer

📍 Engineering of the Hydraulics of Equipment and the Environment, Tunisia

Raghda MESTIRI, Engineer

📍 Engineering of the Hydraulics of Equipment and the Environment, Tunisia

Reviewer

Emna GARGOURI-ELLOUZE, PhD

📍 National School of Engineers of Tunis, Tunisia

Nahed MSAYLEB, PhD

📍 Lebanese University, Faculty of Agriculture and Veterinary Sciences, Lebanon

Supervisor

Bechir BEJAOU, PhD

📍 National Institute of Marine Sciences and Technologies, Tunisia

LAYOUT

HouaidaBOUALI, Engineer

📍 National Institute of Marine Sciences and Technologies, Tunisia

Mohamed Ali BRIKI, Engineer

📍 Coastal Protection and Planning Agency, Tunisia

Index

Index	iv
List of figures	v
List of tables	vi
Abstract	vii
I. Introduction	1
II. State of the coast of DJERBA	2
II.1. A diversified morphology	2
II.2. An eastern facade with sandy beaches	4
II.3. Diverse coastal ecosystems	8
II.4. A rich and diverse archaeological cultural heritage	9
III. Constraints and anthropic pressures	12
III.1. Overcrowding and congestion on the island	12
III.2. Rapid and uncontrolled urbanization on the coast	13
III.3. A traumatic tourism development	13
III.4. Polluted wastewater discharged into the sea	15
III.5. Overfishing and uncontrolled fishing practices	15
IV. Vulnerability of hillsides to flooding due to Climate Change impacts	17
IV.1. Introduction	17
IV.2. Vulnerability of the coastline to erosion	17
IV.3. Vulnerability to Flooding	21
IV.4. Socio-economic Vulnerability	23
V. Coastal Resilience and Management Strategies	24
V.1. Protection actions against marine erosion	24
V.2. Other actions related to the coastline of Djerba	26
VI. Conclusions	27
References	28

List of figures

Figure 1. Djerba archipelago (APAL/PNUD,2012)	2
Figure 2. The different morphological facies of Djerba island coastline (APAL/PNUD, 2012)	3
Figure 3. Morphology of the beaches of the eastern facade of Djerba Island and corresponding coastal dynamics (APAL/PNUD, 2012)	5
Figure 4. State of the beaches in Djerba and areas affected by erosion. From Vulnerability Map Study (APAL/PNUD, 2012)	7
Figure 5. State of the beaches in Djerba and areas affected by erosion	7
Figure 6. Low coastal wetlands of Djerba Island (blue shaded areas)	9
Figure 7. The main ancient sites and Borjs still preserved and not having undergone significant transformation in Djerba(1- El Gantra (Meninx); 2-Soug El Guebli; 3- Sidi Garouss; 4-Lella Hadrhria; 5-Ghizene; 6-Guellala;7- Ghardaia ; 8-Henchir Bourgou; a-Borj El Kbir; b-Borj Kastil)	10
Figure 8. Punic tombs at Souq elGuebli dated to the 3rd century BC (According to the Ministry of Culture and the National Institute of Tunisian Heritage)	10
Figure 9. One of the hypogea, considered protohistoric, dug in the Tyrrhenian sandstone of the root of Terbella peninsula (ANPE, 2017)	11
Figure 10. Djerba - evidence of a workshop of manufacture of the purple	11
Figure 11. Administrative division of Djerba Island	12
Figure 12. Urban component development in Djerba Island	13
Figure 13. Djerba - landing of “pirates” in the protected area of Rmel (http://safira-palms-zarzis.com)	14
Figure 14. Vulnerability map of Djerba for the variable’s topography, geomorphology, coastal dynamics, and occupation of the back coast	18
Figure 15. Global vulnerability map of Djerba Island	19
Figure 16. Dead palm tree in the middle of a wetland; a frequent situation both in Djerba and in the Kerkennah Islands (Photo credit: Oueslati, 2016)	21
Figure 17. Areas potentially flooded by the SLR by 2100	22
Figure 18. South-east zone of Djerba (Aghir) protected by groins	25

List of tables

Table 1. Djerba archipelago	2
Table 2. Coastal wetlands of Djerba Island	8
Table 3. Numbers on tourism in Djerba in 2018	14
Table 4. Distribution (in km) of the vulnerability index for the different criteria in Djerba Island	20
Table 5. Geographical distribution of the overall vulnerability index in Djerba Island....	20
Table 6. Land use in the vulnerable areas of Djerba	22
Table 7. List of ongoing projects in Djerba Island	26

Abstract

Djerba Island has always been known for its diverse morphological variety. In fact, it encompasses a picturesque eastern facade with sandy beaches, along with its rich and varied archaeological cultural heritage. Yet, global warming has become unequivocal in this island, and has caused many negative impacts both on the coastal environment and natural resources. Indeed, it is also characterized by several anthropogenic constraints such as: overpopulation, congestion, rapid and uncontrolled urbanization on the coast, as well as traumatic tourism development, polluted wastewater dumped into the sea, overfishing and uncontrolled fishing practices as well as the sea level rise due to climate change effect. Thereby, becoming more and more threatened by coastal erosion and flooding. For instance, more than half of the beaches are being clearly eroded and some sites have ended up losing their natural beach, while others have lost their socio-economic value. In fact, these beach losses and infrastructure degradation have ultimately led to significant jobs losses related to tourism in Djerba. To minimize the island's vulnerability, several actions and projects have been developed to contain marine erosion.

I. Introduction

This document is the deliverable of phase III relating to the mission “Climate Change (CC) and morphological stability in tourist areas in Djerba” which is part of the Natural Ecosystems Evolution Analysis Project” in relation to the Threats and Factors Favorable to maritime and coastal tourism development at the national scale.

- In accordance with the TDRs, the objective of this deliverable is:
- To highlight the various threats related to the tourist areas morphological stability in Djerba.
- To provide an overview of the areamorphology.
- To describe both the coactulization and urbanization phenomena as well as the types of tourist activities in Djerba.

Obviously, climate change has become a confirmed phenomenon on the global scale. It has become strikingly clear through several phenomena such as the increase in atmospheric and ocean temperatures as well as the average sea level significant rise.

Besides, climate change is likely to amplify the natural pressure that perpetually shapes the coastal domain, through both the coastal erosion processes and through the low-lying areas marine submersion. Consequently, this could have negative and irreversible impacts on the coastline morphological balance, on the marine and coastal ecosystems sustainability, as well as the natural resources abundance and the coastal infrastructure stability.

On the Tunisian scale, the reality of global warming has become unequivocal. Many negative impacts both on the coastal environment and on the natural resources are already obvious mainly on the Tunisian coasts. Indeed, they are clear through the instabilities observed on the coastline morphological forms, on the low-lying coastal areas floods, and on the latest appearance of several exotic species within the marine environment at the expense of native species (<https://planbleu.org/wp-content/>).

To achieve the objectives, the following chapters are going to be clearly presented in the present deliverable:

- Coastal type and trends in morphological evolution.
- Natural ecosystems of coastal areas.
- Anthropogenic activities (coactulization, coastal/maritime tourism, aquaculture...).
- Identification of areas likely to be affected by climate change.
- Effects of climate change on coastal areas (erosion, loss of beaches...).
- Risks and impacts of climate change on coastal areas.
- Impacts of climate change on socio-economic sectors (focus on tourism).
- Mitigation and adaptation (policies, programs, projects: coastal protection measures, coastal resilience policies...) and their effects on coastal/maritime tourism.

II. State of the coast of DJERBA

II.1. A diversified morphology

Djerba is the main island of an archipelago. It consists of three islets, Gataïya El Gharbia, Gataïya El Gueblia and Jlij as well as several other small islets which emerge at low tide between BorjCashtil and the coast of Zarziss, forming a chain parallel to the road of El Kantara, linking the island to the mainland (Oueslati, 2016).

Table 1. Djerba archipelago

Island system	Nb.	Names	Form	Surface (ha)	Coastal line (m)	Min. distance to the mainland (m)	Max. coastal line (m)
Djerba		Djerba	Island	51,400	189,000	-	-
		Gataya El Gueblia	Island	71.7	4,532	900	2
		Gataya Bahria	Island	145	6,450	1,350	5
		Jlij	Island	148	5,817	4,400	1
		BorjJlij	Island	1	563	515	-
		Bin El Ouediane	Island	196	16,794	1,700	-
Total	6			51,962	223,156	-	-

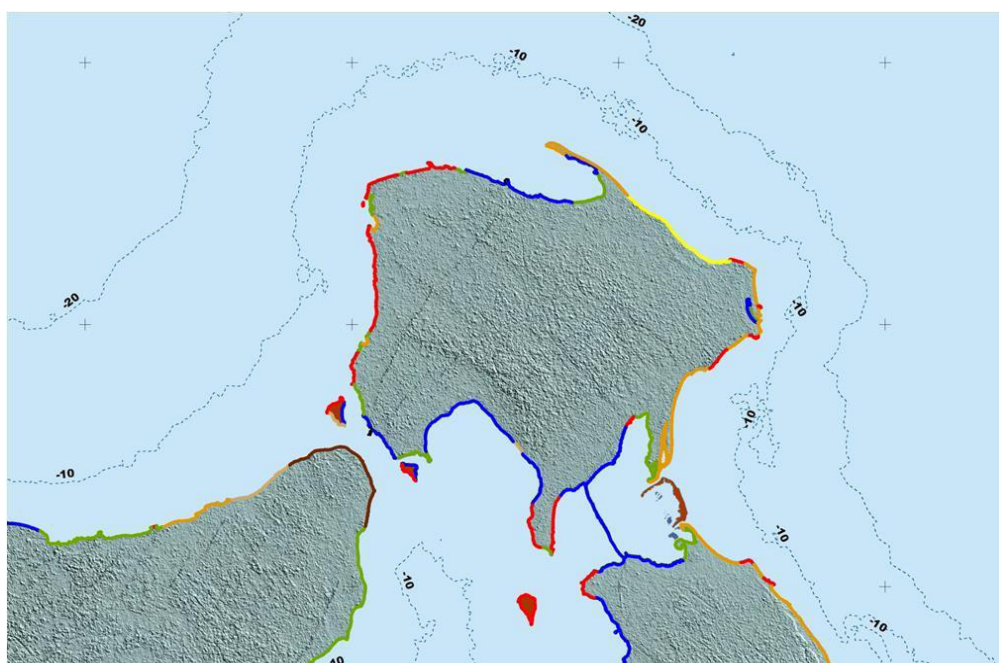


Figure 1. Djerba archipelago (APAL/PNUD,2012)

On the shores of Djerba and on its neighboring islets, there are four main types of forms: small cliffs, low rocky coasts, beaches, and sea marshes.

- **Low rocky coasts:** they are much more frequent than cliffs. In fact, they are well represented on the main island's western side and in part of Gataya El Bahria and Jlij islets. In the southern and eastern segments of Djerba, they are limited to Tarbela peninsula shores and part of the Aghir-Topkhana coast. They are clearly distinguished by two geological formation types: the limestone crust of the ancient Quaternary and the marine sandstones attributed to the Tyrrhenian or Holocene.
- **The sandy beaches:** they are often shaped either without important dunes or with little developed ones. They can be found in the small creeks that dot the western coastline, but it is on the eastern and north-eastern facades that they show the maximum of their extension. In fact, they are (in their natural state) at least a few decameters wide and they are usually accompanied by a bordering dune that can locally exceed 3 meters high. Today, they show the maximum of their development in the spit of Ras Errmal.
- **The maritime marshes:** they occupy an important place and owe their genesis to the tide. They are found mainly in the southern part of the island and in the segments of coast sheltered by peninsulas (peninsula of El Gastil) or coastal spires (Ras Errmal, Lella Hadhria).
- **The cliffs:** they are usually rare and always not very important by their command which is only about 3 or 4 m. Yet, they are rather varied by their lithologies, and they are heterogeneous. In fact, the latter are however dominated by unequal resistance material (clays, sandstone, sand, and silts) favoring an effective differential erosion. This geographical form is in fact represented only in the vicinity of Guellala and punctually on the side of Ras Rougga, Torbkhana and Sidi Salem.

Djerba Island has a coastline of 189 km in direct contact with the sea and that consists of 6 types of morphological facies as shown on Figure 2:

Low rocky coast	37 km
Coasts with dune field beaches	10 km
Coasts with beach without dune field	42 km
Low coasts with maritime marshes	34 km
Other low furniture ribs	57 km
Small cliffs	1.5 km
<u>Other</u> hard coast	8 km

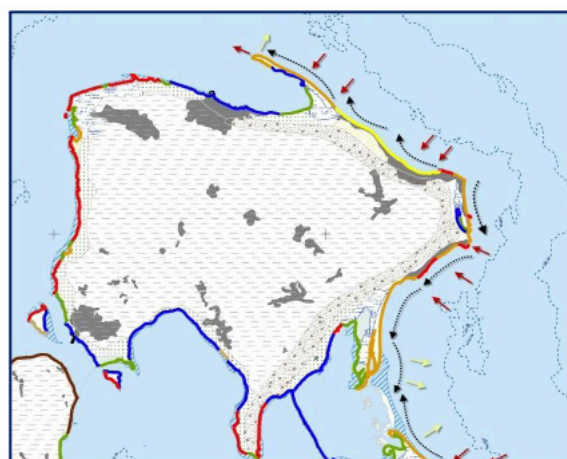


Figure 2. The different morphological facies of Djerba island coastline (APAL/PNUD, 2012)

II.2. An eastern facade with sandy beaches

Even though Djerba Island shoreline lies along 189 km, it has only 52 km of beaches located on the north-east and south-east flank, and it shapes Ras Errmal Northern spit to Borj El Kastil Southern tip.

On the east side, there lies all the tourist and hotel infrastructure concentration which is characterized by:

II.2.1. Active sediment dynamics

- **Figure 3 shows two coastal transit directions:** In fact, in the northeast flank: the transit is directed north (points to Ras Errmal), while in the southeast flank: the transit is directed to the south (points to the spit of El Kastil).
- **The North-East flank:** This shoreline which extends from Ras Tobyhanna spit to RasErrmalspit does not have the same morphology nor the same dynamics neither the same occupation type by tourist developments. Going from east to west, it is possible to distinguish the following two sectors:
 - **From the hotel Dar Djerba to the rooting of the arrow:** It is in this area where more than 80% of Djerba hotel infrastructures are established. The beach is sometimes still quite extensive, especially where the hotel units are not too close to the shore. However, there are various signs of de-migration. These indications correspond to rocky outcrops that start to multiply on the foreshore. In fact, they become exhumed as the sand which surmounted them is removed by the waves. Going westward, some hotel developments have often ventured too far towards the seashore, encroaching on the dune ridge at the top of the beach (*Hôtel les Sirènes, etc.*). This evolution can be seen in the continuous reduction of the beach's width as well as the fact that the bordering dune is often cut into a cliff. Some beachfront constructions have become within reach of the waves even during ordinary storms (Sidi Mehrez residence). Another ignored indicator is the multiplication of rocky outcrops specifically on the foreshore (beige sandstone of the Holocene dune). That is to say that these are always components of materials exhumed by the waves as the beach profile is lowered by erosion. Indeed, this phenomenon is extending more and more to some hotels' shores.
 - **The spit of Ras Errmal:** Elongated SE-NW in the shape of a peninsula, this spit is now nearly 8 km long and has a rather varied morphology. Its transverse profile reveals two areas that are highly differentiated both by their shape and by their sedimentology. Besides, on its side open to the sea and exposed to the most active winds, a sandy beach dominates, relayed by a well-developed dune line. On its inner side, the place is given to wetlands type maritime marsh traversed by various tidal channels or sabkhas type regularly flooded during the rainy season and during strong storms. The morphology varies as

well in the longitudinal profile. Thus, the sandy constructions and especially the dunes show their most important development in the central part of this spit with a width varying from 200 to 500 m. On the side of the spit root, the sandy body is wider, but the dune part loses volume and continuity. Towards the tip, the shape is that of a wide but much crushed barrier beach with almost no dunes. Since the 1990s, the spit has lengthened to gain almost one kilometer.

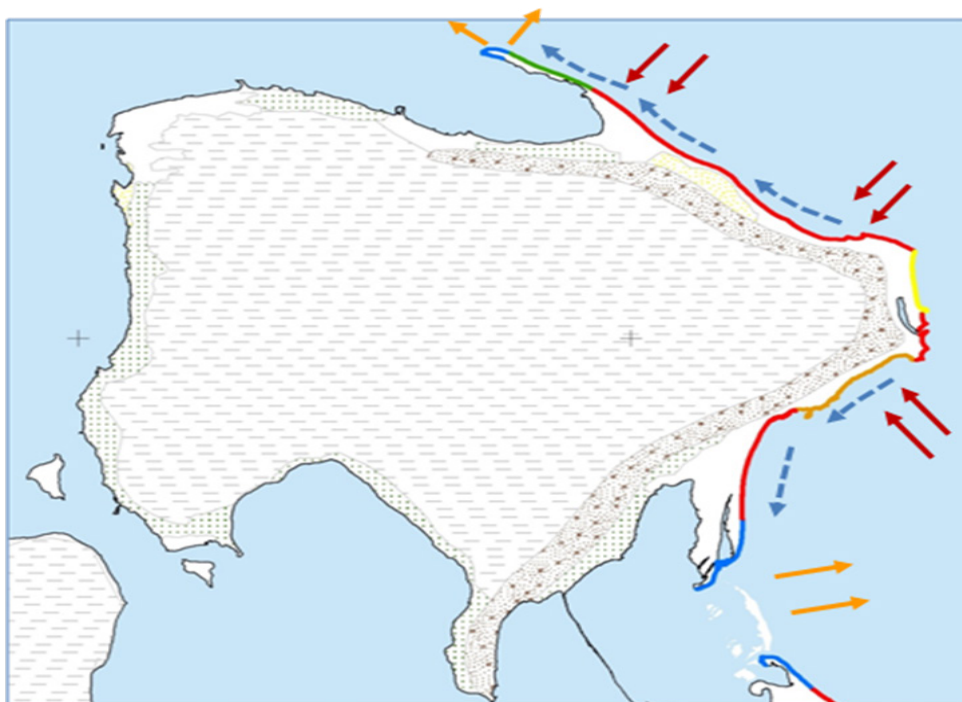


Figure 3. Morphology of the beaches of the eastern facade of Djerba Island and corresponding coastal dynamics (APAL/PNUD, 2012)

Shorelines in red (areas undergoing net erosion), blue (undergoing net nourishment), orange (disappeared beaches) and yellow (stable beaches)

- **Southeast flank:** There is some symmetry between the previous section and the southeast flank. As for the previous section, the area sedimentary regime can be divided into two parts. The first relates to the northern section from Sidi Garous (Lella Hadhria) to Aghir. The second is related to the spire of El Kastil which goes from Aghir to the old fort of Aghir.
 - **From Lalla Hadria point to Aghir:** This area is also equipped with several hotel infrastructures but with a lower density than the previous one. On almost five kilometers of coastline, a rocky coastline has replaced the sandy beaches. Consequently, several hotels, even among those built in recent years, have found themselves almost without a natural beach. To face this situation, attempts to protect the beach began in the early 1990's. At first, it was a question of simple

earthen dikes or informal accumulations of boulders on the shore. Today, we are witnessing other types of interventions, especially the attempts of artificial recharging and the groins multiplication carried out in an artisanal way without prior studies. Concerning the groins, there were only four in the early 1990's: three short ones at the height of the hotel Sidi Slim and another one, much larger, in front of the hotel Palmariva. Since then, there has been a real race for spikes. Convinced of the “miracle” effect of this type of work, the hoteliers have each sought to have their own. Currently, there are more than 20 cob structures with a total length of about 1800 m. The hotels that have not yet installed their groin have been penalized. Their shoreline has become more and more rocky and stony, sometimes even in the foreshore area.

- **The spit of El Kastil:** it extends over a length of more than 5 km; this spit is shaped in the form of a peninsula extending along the north-south direction. On the seaside, the exposed beach is sandy and presents itself as a barrier between the sea and the wetland of El Kastil.

II.2.2. An alarming state of erosion

The report is alarming: more than half of the beaches are in clear erosion. In fact, this erosion concerns the small cliffs evolving into soft rocks of the sector of Guellala as well as those around Ras Rougga in the tourist area. But it is for the sandy beaches of the eastern and north-eastern part of the island that it has been clearly traced.

Indeed, the literature indicates that the beaches in this part of the island are being eroded, which is not the case with the distal part of Ras Errmal spit and some other sections located further into the south. Several references clearly show that the phenomenon is not recent and that it has been discovered since the 1970s. They were frequently and straightforwardly indicated in the 1980s. While some sites ended up losing their natural beach, other sites' waves have started directly attacking the external walls of the constructions. This has sometimes forced, as in the case of the Jazira Hotel, voluntary destruction of some building parts. The recent protective structures multiplication, including groins and riprap, also reflects the accentuation of the problem.

In fact, the situation can be explained by natural data, including the lack of sediment, since these beaches are made of inherited material which is not renewed enough. Yet, an important part of responsibility has been attributed to man, particularly by the sea front development multiplication and by the beach pressure and the dunes destruction as well as the non-adapted protection works multiplications. In fact, the degradation accelerates as soon as the waves start to attack the developments, especially the hard constructions.

The main literature references available show that beaches are already subject to net erosion and represent about 40% of all beaches in the area. On one hand, those showing signs of nourishment represent only a little over 3%. Around 77% of the beaches are largely eroded, “deformed” or even non-existent, more than three quarters of the beaches of Djerba. Only four kilometers (a little more than 7%) still resist. On the other hand, 8 km is fattening.

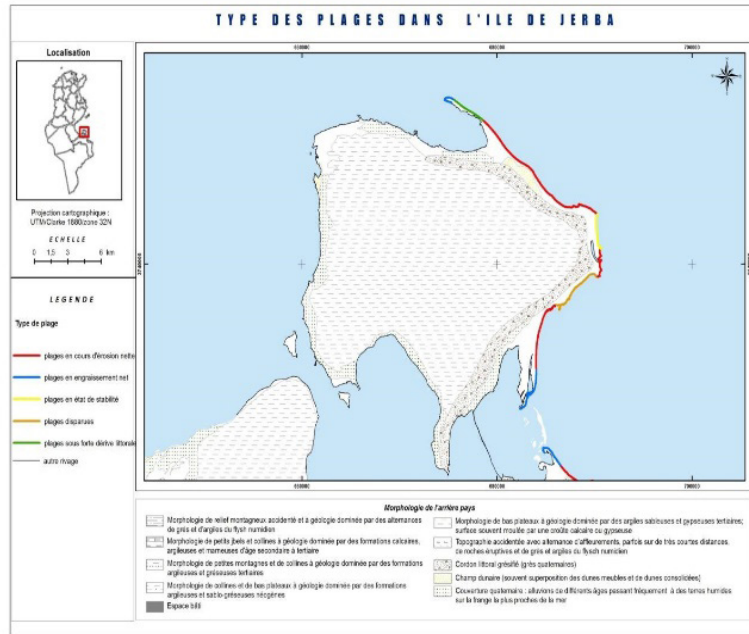


Figure 4. State of the beaches in Djerba and areas affected by erosion. From Vulnerability Map Study (APAL/PNUD, 2012).

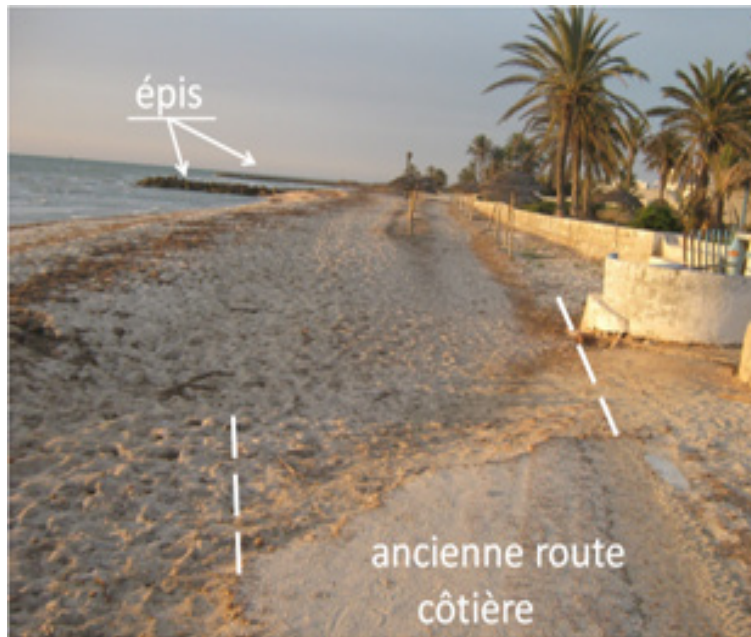


Figure 5. State of the beaches in Djerba and areas affected by erosion

Here, an example of the island tourist coast, we recognize the old coastal road crossed by the coastline and whose location is now in the beach area. We also recognize, in the last plan, protection groins (ANPE, 2017).

1. Beaches in net erosion 28 Km
 2. Beaches in net fattening 8 Km
 3. Beach in stable condition 4 Km
 4. Endangered beaches 8 Km
 5. Beach under strong littoral drift 4 Km
- Other segments in net erosion

II.3. Diverse coastal ecosystems

Djerba Island is very rich in low coastal wetlands that are vulnerable to submergence induced by sea level rise SLR. On a total area of 51,000 hectares, the island has 600 hectares of low coastal areas vulnerable to sea level rise (Table 2 and Fig. 6):

- Sabkhas: 2210 ha
- Shores: 700 ha
- Estran: 3110 ha

Table 2. Coastal wetlands of Djerba Island

Wetlands	Name	Surface (ha)	Surface (ha)
Sebkha	Sebkha Ras Errmel	306	2,210
	Sebkha Lella Hadhria	149	
	Sebkha El Kastil	848	
	SebkhaJlij (Aéroport)	906	
Shores	Schorre Boughrara	214	700
	Schorre Djerba Aéroport	67	
	Schorre Djerba Ouest	121	
	Schorre El Kantara	508	
Estran	Estran Djerba Aéroport	384.3	3,110
	Estran Djerba Ouest	403.0	
	Estran Gataya Bahria	196.6	
	Estran Gataya Guiblia	46.3	
	Estran Jlij	412.2	
	Estran Gallala	505.0	
	Estran El Kantara	1,165.2	
Total			6,000

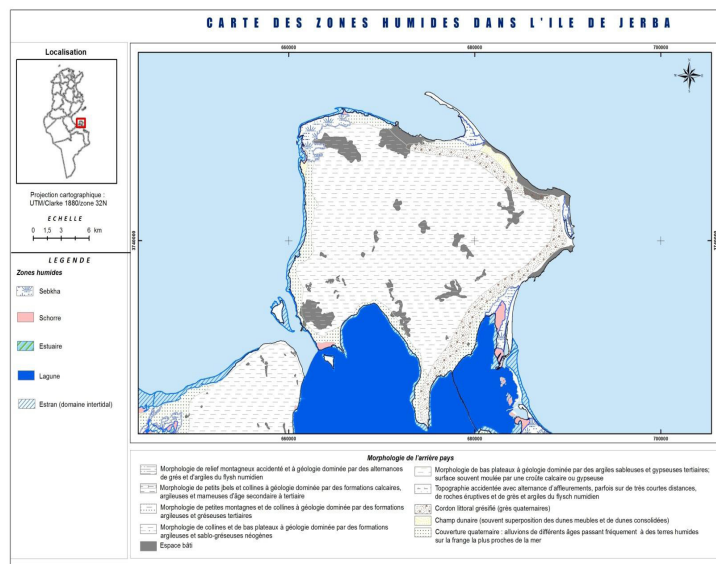


Figure 6. Low coastal wetlands of Djerba Island (blue shaded areas)

II.4. A rich and diverse archaeological cultural heritage

Djerba Island is considered as the richest island in Tunisia in terms of archaeological remains. It is also known for its architectural uniqueness and for its specific clothing and culinary heritage.

Concerning the archaeological aspect, it is clearly noted that the prehistoric man traces have not yet been the object of publications. In addition, the historical age vestiges have attracted attention at different levels and are sometimes valued in tourist activity. The best known are inherited from antiquity and from the period of the Turkish-Spanish conflicts. They are mostly found on the coast or in areas close to it.

For the vestiges dating from antiquity, only Meninx are frequently mentioned. Yet, several other important sites still exist. In the interior of the island, some isolated monuments have managed to escape burial like some funerary monuments that are located behind Meninx, near the road to Cedouikèche (Ghardaia), or the one of Henchir Bourgou (between HoumetEssouk and Midoun) which would go back to the Numidian period. Besides, other traces of the ancients still exist underground. This is the case of hypogea, considered protohistoric (Akkari, 2004) and dug in the sandstone (Chekhech) of the Tyrrhenian coastline and which can be seen at the root of the peninsula of Tarbela, along the road linking Guellala to Meninx.

The periods of insecurity are well known thanks to numerous writings relating to the battles that took place in the region. But their most direct traces, on the ground, are the monuments with defensive vocation which punctuate the coast: mosques, marabouts and especially citadels. The best preserved of the latter are Borj El Kbir or Borj Ghazi Mustapha in HoumetEssouk, Borj El Gastil at Peninsula southern end and BorjJlij in the

northwest of the island. The bibliography reports a larger number but most of them have been destroyed and sometimes only barely recognizable traces remain. In addition to the above-mentioned, BorjMersa Ajim, BorjTerbella, Borj El Kantara, BorjAghir and Borj El Agreb are reported. The latter is located on the sea that separates the island from the mainland at the height of Terbella peninsula.

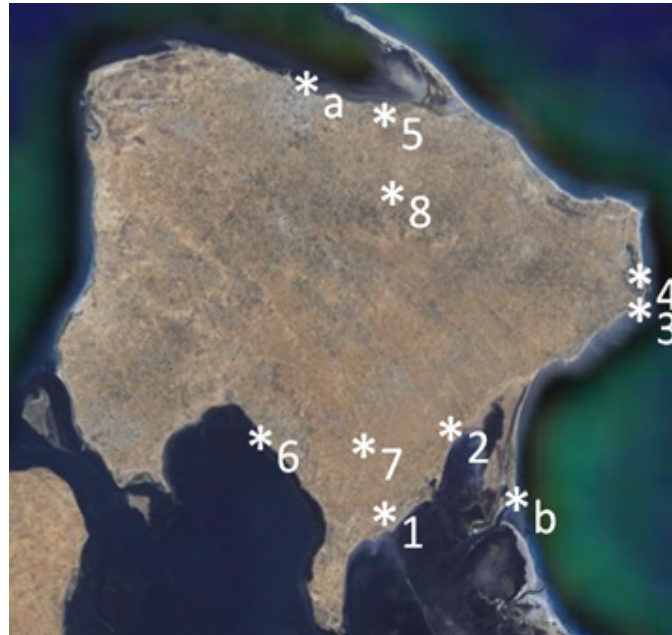


Figure 7. The main ancient sites and Borjs still preserved and not having undergone significant transformation in Djerba(1- El Gantra (Meninx); 2-Soug El Guebli; 3- Sidi Garouss; 4-Lella Hadhria; 5-Ghizene; 6-Guellala;7-**Ghardaia**; 8-Henchir Bourgou; a-Borj El Kbir; b-Borj Kastil)



Figure 8. Punic tombs at Souq elGuebli dated to the 3rd century BC (According to the Ministry of Culture and the National Institute of Tunisian Heritage)



Figure 9. One of the hypogea, considered protohistoric, dug in the Tyrrhenian sandstone of the root of Terbella peninsula (ANPE, 2017)



Figure 10. Djerba - evidence of a workshop of manufacture of the purple

III. Constraints and anthropic pressures

The constraints and anthropic pressures are significantly associated with socio-economic activities, urbanization, and infrastructure, which may compromise the harmonious development of the island.

III.1. Overcrowding and congestion on the island

The island inhabitants are around 140,000, and they spread over the three delegations which correspond to three municipalities with different positioning:

- Djerba-HoumtEssouk, this city is considered the “capital” of the island with 65,000 inhabitants for the whole municipality.
- Djerba-Midoun, it is the closest tourist activities center with more than 50,000 for the whole municipality.
- Djerba-Ajim is more backward in relation to the dynamics of the island, with 25,000 inhabitants for the whole municipality.

The human concentration phenomenon on the island is mainly due to the seasonal increase in the coastal population, related to emigration, the arrival of a million tourists per year and the local population. Indeed, the main indicators are in red: the coastal linear occupation is 25.45 on average (2.28 for Tunisia) with a tourist density of 1,485 tourists per km² (94 for Tunisia). Consequently, the social pressure indicator is 5.45 against 3 at the national level. All the above indicators will continue to increase, which will certainly aggravate the fragility of the environment.



Figure 11. Administrative division of Djerba Island

III.2. Rapid and uncontrolled urbanization on the coast

The spatial sprawl characteristic of the island urbanization and its evolution is one of the main factors responsible for the extension of agricultural areas on the one hand, and the low residential densities on the other hand. This space mode occupation reflects the population preferences for suburban housing, strong consumer of space, and prevalence of an uncontrolled urbanization.

The traditional architectural heritage characteristic of the island is now abandoned in favor of a more standard typology that has been introduced following the opening of the island to tourism and influences from the mainland. Moreover, we are witnessing the extension of anarchic habitat that marks consequent ruptures in the Djerba landscape affecting its harmony and contributing to its environmental degradation. This situation, characterized by the traditional buildings' abandonment and deterioration, would eventually lead to the disappearance of these monuments and the loss of the specific identity that conveys the architectural heritage characteristic of the island.

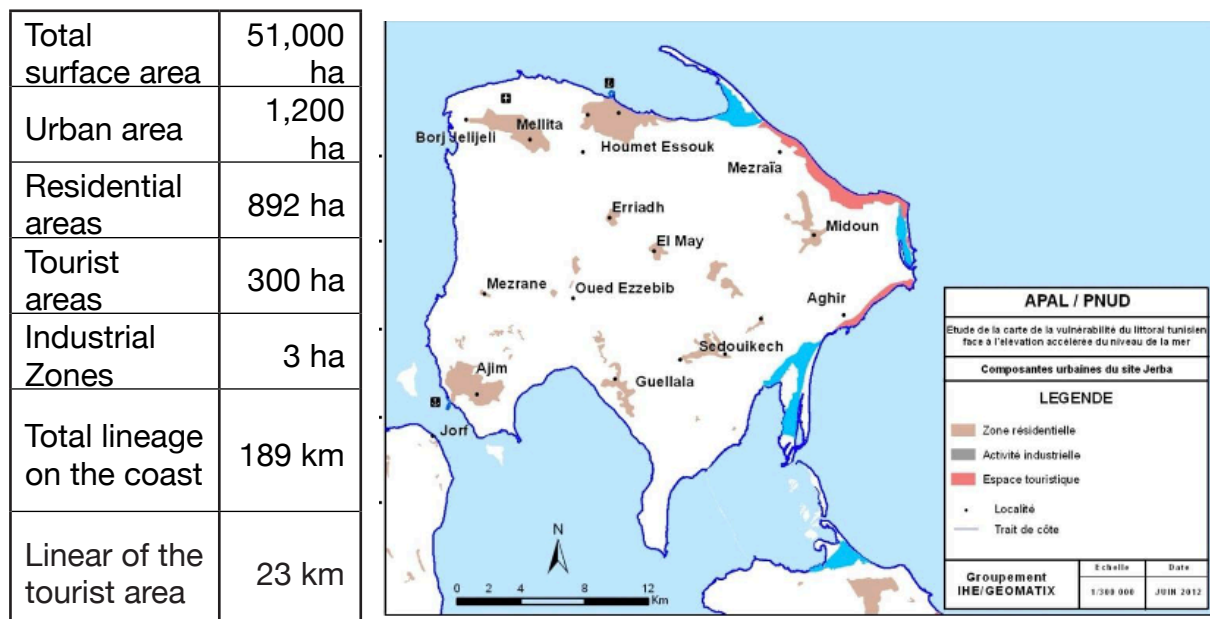


Figure 12. Urban component development in Djerba Island

III.3. A traumatic tourism development

The most striking element of Djerba economic development is the rapid evolution of the tourist sector. It is materialized by the privatization of 23 kilometers of coastline in the northeast of Djerba, and their occupation by hotel units whose capacity reaches about 34000 beds for 73 units and this, in addition to the 44 hotel units of HoumetEssouk which total a capacity of 8650 beds.

In 2019, Djerba recorded 7 million overnight stays. Table 3 provides the 2018 statistics for this sector:

Table 3. Numbers on tourism in Djerba in 2018

Global arrivals	941,294
Tourist nights	5,877,490
Direct jobs	8,652
Occupancy rate	53%

This has resulted in an unbalanced and unstructured environment, particularly:

- **For the terrestrial environment:** progressive abandonment of garden maintenance, huge conglomerates constructions for personal profits.
- **For the marine environment:** indirect eutrophication but more important than Gabes Gulf waters.
- **For the coastal environment:** concrete dunes bordering the Gabes Gulf, have caused the grass beds destruction already weakened by the Gulf pollution and the significant coastal line decline.

The seasonal increase in the coastal population is mainly linked to the arrival of one million tourists per year. Thereby, leading to the island overcrowding and congestion. The main indicators are highlighted in red: the coastal linear occupation is 25.45 on average (2.28 for Tunisia) with a tourist density of 1,485 tourists per km² (94 for Tunisia). All the indicators mentioned continue to increase, which further aggravates the Djerba environment degradation.



Figure 13. Djerba - landing of “pirates” in the protected area of Rmel (<http://safira-palms-zarzis.com>)

III.4. Polluted wastewater discharged into the sea

The wastewater disposal for dwellings not connected to the sewerage system is mainly done in septic tanks and cesspools which are supposed to be emptied by tanker trucks and transported to the wastewater treatment plant WWTP. This situation represents a source of soil pollution and groundwater contamination. The connection of all the areas must be a priority for the managers of this island.

At the level of the wastewater treatment plants WWTPs, the discharges of treated wastewater (the treatment works approval TWA) are most often made in the Sabkhas. These discharges are sources of pollution for both the water table and the environment, knowing that wastewater should not be discharged into closed water bodies or sites where water circulation is limited. The discharge of treated municipal effluents TMEs must be effectively managed to limit pollution and to ensure that the effluent is perfectly filtered, for which tertiary treatment of the water from the WWTP is recommended. This process is relatively costly but can be envisaged with the valorization in the island's economic activities (in agriculture: irrigation of forage crops, fruit trees, *etc.* and in the tourist sector: irrigation of green areas and golf courses, *etc.*).

Such a situation of environmental deterioration highlights the enormous weight of anthropic pressures on the ecosystem. The constraints, of all kinds, are mainly of a "chemical" order by:

- Hyper eutrophication of the waters of the Gulf of Gabes which rush into the lagoon through the wide channel of Ajim. Thereby, leading to environmental asphyxiation due to the funds plant cover reduction. This in its turn leads to endogenous species extinction and to ecosystem destruction.
- Pollution due to the direct or indirect household dumping of hotel and hospital waste from all over the island in the Guellala area.

III.5. Overfishing and uncontrolled fishing practices

The uncontrolled fishing, the bottom scraping as well as the fishing units' plethora have all led to the fish stocks' overexploitation and in certain cases, to a real rupture in greatest commercial interest species stock. The fisheries production on the island marine facades has slightly increased over the recent years. This would indicate that the aggressions suffered by the marine environment would be irremediable.

Most of the problems associated with fishing in this island are the following:

- The poor environmental conditions prevailing in the Gulf and specifically in the waters surrounding the island archipelagos. This is concretized by the ecosystem's flora destruction and the progressive bottom desertification, generated by the environment suffocation with nutritive salts.

- The overexploitation of marine resources mirrored through:
 - An excessive fishing effort (too many boats) in relation to the resource.
 - The increasing use of destructive gear such as the “kiss” in an environment that is strongly weakened by pollution.

This has resulted in a drastic decline in the fishery resources of this area of the Gulf with a strong decrease in the tonnages of shrimp and octopus’ fisheries.

IV. Vulnerability of hillsides to flooding due to Climate Change impacts

IV.1. Introduction

With sea level rise (SLR), a new state of equilibrium will be reached and will be likely resulting in a loss of sand and consequent reduction in beach width or even complete disappearance. In addition to these physical phenomena, reduced precipitation, and terrestrial sediment inputs, which are sources of solid matter supply, will contribute to the threat to beaches. This will not only impact public bathing areas, but also tourist areas. Djerba Island, being part of the most threatened regions by the rise in sea level (along with the Kerkennah Islands and the low areas of the bottom of the Gulf of Hammamet) is seriously threatened to lose all its sandy beaches.

IV.2. Vulnerability of the coastline to erosion

The application of the coastal vulnerability concept to the different parameters related to erosion (coastal topography, coastal geomorphology, coastal dynamics, and occupation) has led to the realization of the following vulnerability maps of Djerba Island.

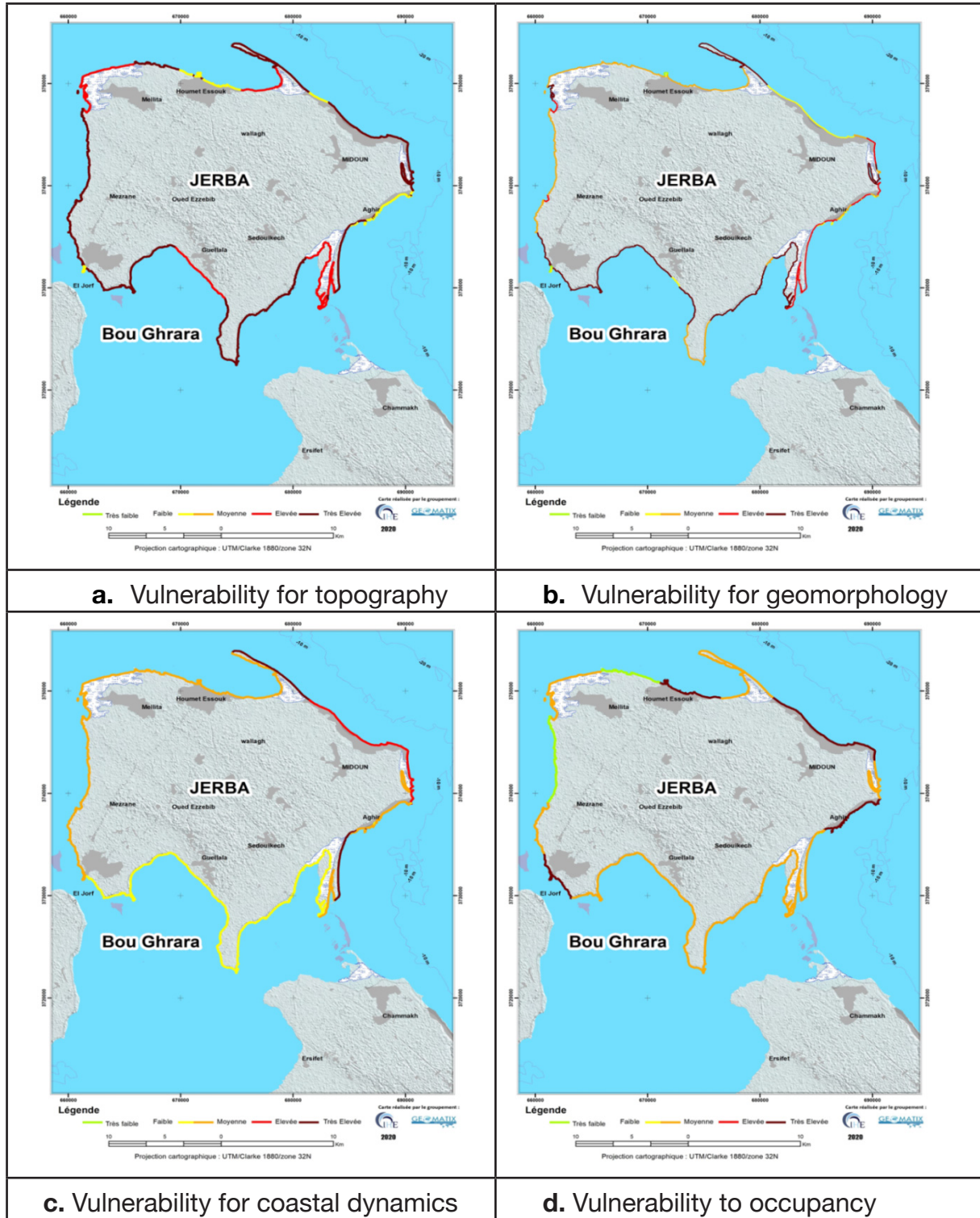


Figure 14. Vulnerability map of Djerba for the variable's topography, geomorphology,

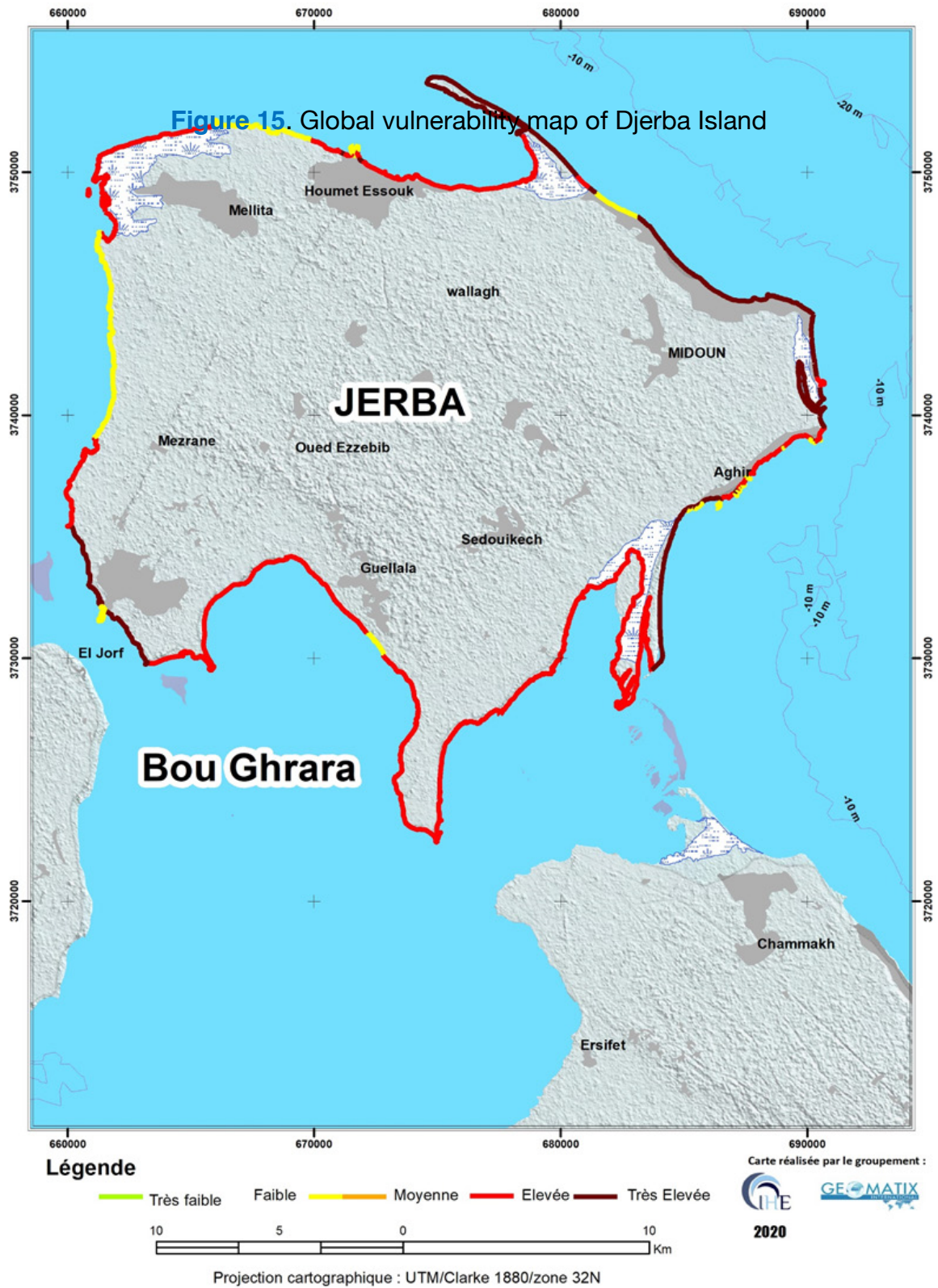


Table 4. Distribution (in km) of the vulnerability index for the different criteria in Djerba Island

Criterion	Very low	Low	Average	High	Very high	Total (km)
	1	2	3	4	5	
Topography	0.0	27.9	0.0	50.0	110.0	188
Shoreline geomorphology	1.6	23.5	56.5	28.7	77.3	188
Coastal dynamics	0	68.2	84.8	17.4	17	188
Land use	17.3	0	124.2	0	46	188

Table 5. Geographical distribution of the overall vulnerability index in Djerba Island

Overall vulnerability level	Index	Sea front	
		km	%
Low	1	3.9	2.08
Average	2	49.2	26.23
High	3	90.5	48.24
Very high	4	44.0	23.45
Total (km)		187.6	100%

From the results of the vulnerability calculation presented in Tables 4 and 5, it is obvious that: almost 23% of the coasts of Djerba island are highly vulnerable (index 4) on a total length of about 44 km.

- About 48% of the coasts of Djerba island are vulnerable with an index 3 and a linear of about 91 km.
- About 26% of the coasts of Djerba Island are of medium vulnerability (index 2) with a linear of 49 km.
- About 2% of the coasts of Djerba Island are of low vulnerability (index 1) with a linear of about 4 km.

The application of Bruun's formula on three stretches of coastline that are given precise bathymetry, for an ENM of 50 cm at the horizon 2100: A decline of 0.66 m/year in the tourist area of El Mezraya was revealed.

- A recession of 0.33 m/year in the tourist area of Sidi Mehrez.
- A recession of 1.00 m/year in the tourist area of Aghir.

IV.3. Vulnerability to Flooding

Low-lying floodplains are extensive. They are represented mainly by wetlands and lowlands on the coasts.

In fact, these lands exist in different parts of the island. But it is only in the south-eastern and north-western sectors that they are highly dominant. They are frequently flooded and can remain inaccessible for many months in a row, especially in years with relatively high rainfall and those with frequent marine storms. Certainly, these lands are still largely unoccupied. Yet, developments have begun to multiply at the expense of some of them. This is the case in the towns of Ajim and HoumetEssouk and in some tourist areas like the hotels located in the Northern part of the sebkha and LellaHadhria.

In Djerba, there are indications of recent submergence phenomena. The main submerged archaeological remains are reported on the southern coast of the island, in the vicinity of Guellala and especially those belonging to the site of Meninx.

Finally, the island shows signs of soil degradation due to the salinization process. As in the Kerkennah islands, the state of the palm trees in the areas close to the shore and the banks of the sabkhas.



Figure 16. Dead palm tree in the middle of a wetland; a frequent situation both in Djerba and in the Kerkennah Islands (Photo credit: Oueslati, 2016)

With a rise of +1 m by the next century, all these wetlands will be submerged by the sea. The map of potentially flooded areas is presented in the following Fig. 17.

The potentially submersible areas cover a total area of about 8760 ha, or about 17% of the total area of Djerba. These lands are distributed as follows:

Table 6. Land use in the vulnerable areas of Djerba

Occupation	Surface (ha)
Airport	36
Hotel complex	335
Crops	2,980
Discharge	41
Natural areas	986
Industrial port infrastructures	52
Habitats	240
Wetlands (sabkhas and schorres)	2,970
Beaches and dunes	1,120
Total	8,760

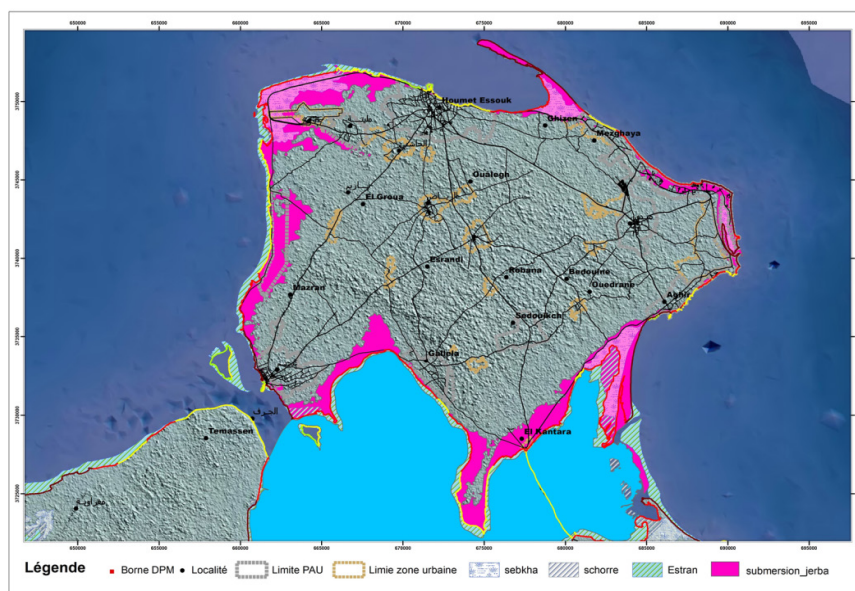


Figure 17. Areas potentially flooded by the SLR by 2100

IV.4. Socio-economic Vulnerability

In Djerba, it is clear that a very large part of the constructions (mainly tourist and leisure establishments, and residential fabrics) are destined for a certain demolition or to a swallowing. In both cases, there will be the disappearance of the sea rise benefits.

The risk of marine submersion of built areas on the coast may also impact the 560 hectares of tourist areas located largely on the eastern side of Djerba Island (427 hectares). These losses of beaches and degradation of infrastructure should be accompanied by a significant loss of jobs related to tourism in Djerba.

Today, it is already known that more than 470 hectares of built territory are already submerged by the sea.

V. Coastal Resilience and Management Strategies

V.1. Protection actions against marine erosion

Djerba Island has two major groups of different morphological features: On the one hand, facies with low coasts and maritime marshes sheltered from swells and, on the other hand, second facies with beaches exposed to an active maritime dynamic.

Regarding the first type of facies sheltered, it is the southern coasts exposed on the lagoon of Boughrara as well as the western coasts open to the Gulf of Gabes and the northern coasts sheltered by the famous spit of Ras Errmal. This coast is relatively sheltered from swells and the corresponding solid transports which are almost null. For this part, the problems are related to submergence and therefore it does not require the realization of protective works against marine erosion.

The situation is different for the second type of facies on the north-east and east sides. Several protective structures of the rock slope type have been installed on the island's coastline, to prevent the sea from advancing in front of several hotels. Besides, very short groins are built to protect the coast against erosion phenomena. On this facade, we distinguish:

- For the north- east and east sections (HoumetEssouk to Sidi Garous):
 - Cavalier HoumetEssouk: 300 m.
 - PalmivellesHoumetEssouk: 200 m.
 - Hotel El Jazira: Longitudinal protection on 120 m.
 - Hotel les Sirènes: Longitudinal protection on 170 m.
 - Sidi Mehrez: Reconstitution of the dunes: 200 m.
 - Sidi Mehrez: Palmivelles 200 m.
 - Sidi Hachani: Ganivelles 280 m.
 - Hotel Sidi Yati Midoun Club: Longitudinal protection on 60 m.
- For the south-east section (Sidi Garous to Aghir) (Fig. 18):
 - More than 20 cobs (Hotel Hari, Laico, Sango, Aghir, *etc.*): 1760 m.
 - Longitudinal protections (riders, walls, *etc.*): 650 m.



Figure 18. South-east zone of Djerba (Aghir) protected by groins

V.2. Other actions related to the coastline of Djerba

The other actions related to the coastline of Djerba are detailed in Table 7.

Table 7. List of ongoing projects in Djerba Island

Title	Objectives	Project manager	Situation
Construction of a seawater desalination plant with a capacity of 50000 m ³ /day, expandable to 75000 m ³ /day	To satisfy the island's drinking water needs until 2030	National Company of Exploitation and Distribution of Water SONEDE	Completed and in operating condition
Doubling of the Roman roadway that connects the mainland to the island	Facilitate mobility between the mainland and the island	Ministry of Equipment and Housing DGPC	In progress
Project of creation of a golf of 100 ha in the zone of Guellala	Integrated project focused mainly on the promotion and development of golf tourism in Djerba island considered to be the most important residential tourist pole in Tunisia	OMEGA DEVELOPPEMENT	Under study
Project of coastal resilience of Djerba island	Establish a system of management and adaptation by flexible methods of the coast of Djerba to the rise in level due to CC and fight against coastal erosion	Coastal Protection and Planning Agency APAL with Global Environment Facility GEF/ United Nations Development Program funding UNDP funding	Studies completed and work not yet done
Study of the protection of the southeast coastline of Djerba against marine erosion	Design of a protection system against marine erosion of a coastline of 10 km between Sidi Garous and Aghir	Coastal Protection and Planning Agency APAL	Studies completed and work not yet done
Protection study of the North-East coastline of Djerba against marine erosion	Design of a protection system against marine erosion of a coastline of 10 km between Sidi Hachani and Sidi Yati	Coastal Protection and Planning Agency y APAL	Summary study carried out
Implementation of a Management Plan for the Ras Errmal Spit	Ensure sustainable development consistent with its status as a sensitive area and RAMSAR zone	Coastal Protection and Planning Agency APAL	Currently being updated
Establishment of a Management Plan for El Kastil Spit	Ensure sustainable development consistent with its status as a sensitive area and RAMSAR zone	Coastal Protection and Planning Agency APAL	Currently being updated
Development study of the sabkha Lella Hadhria	Creation of a permanent water body, a marina, and a tourist development with a hotel capacity of 6000 beds	Tourism Office	Studies completed and work not done
Study to improve the quality of water in the lagoon of Boughrara	Improvement of water circulation and water quality	General Directorate of Fisheries and Aquaculture DGPA	Under study

VI. Conclusions

Djerba island belongs to the Governorate of Medenine and it extends over a total area of 51,000 hectares divided administratively into three municipalities Houmet Essouk, Midoun and Ajim. Its shoreline, with a total length of about 189 km, includes only 52 km of beaches located on the northeast and southeast flank from the northern tip of the spit of Ras Errmal to the southern Borj El Kastil spit.

The main literature references available reveal that these beaches have already been subjected to net erosion and they represent about 40% of all beaches in the area. Additionally, those that show signs of fattening represent only a little over 3%. Yet, 77% or even more than three quarters of the island's beaches are largely deformed.

The most striking element of the economic development in Djerba is the rapid evolution of the tourist sector. It is materialized by the privatization of 23 kilometers of littoral in the north-east of Djerba, and their occupation by the hotel units of a capacity of more than 34,000 beds.

Today, already beset by the sea on a large fringe of its coastline, Djerba Island is considered particularly vulnerable to the effects of the SLR induced by climate change. Sixteen percent (16%) of the island is threatened by submergence because of ENM and more than three quarters of its beaches are deformed and undergoing erosion.

The invasion of low-lying coastal areas will result in a "marinization" of these environments (formation of small bays with a consequent migration of the foreshore towards the interior of the island).

These lands, potentially floodable, include urban spaces, hotel infrastructures, cultivated agricultural lands, foreshore exploited by women for the collection of clams, coastal wetlands with a brand landscape for the island.

Considered, a century ago, as one of the most harmonious landscapes with a perfect combination of a skillfully controlled nature and an original architecture marked by a great serenity, the Djerbian landscape is strongly threatened both by man irresponsible urbanization, which is often anarchic, intense concrete coastline especially in the eastern part of the island, and by the SLR which risks amplifying all the problems already mentioned.

References

ANPE, 2017. Elaboration de la stratégie de Gestion durable des zones insulaires tunisienne. Etude réalisée par IHE pour le compte de l'ANPE.

Akkari, 2004. Le paysage funéraire libyco-punique de l'île de Djerba: les caveaux de Mellita. Reppal, 13:5-33.

APAL/PNUD, 2012. Étude de la carte de la vulnérabilité du littoral Tunisien due aux Changements Climatiques - Etude réalisée par le Groupement IHE-GEOMATIX pour le compte de l'APAL.

Oueslati A., 2016. Les îles de la côte orientale de la Tunisie - Dynamiques environnementales, 38. <http://journals.openedition.org/dynenviron/746>. DOI: 10.4000/dynenviron.746.

<http://safira-palms-zarzis.com/vivre-une-experience-enrichissante-et-hors-du-commun>

https://planbleu.org/wp-content/upload/2016/01/Rapport_National_Tunisie_October_2015.pdf

DISCLAIMER

The present document has been produced with the financial assistance of the European Union under the ENI CBC Med Program. The contents of this document are the sole responsibility of *National Institute of Marine Sciences and Technologies* and can under no circumstances be regarded as reflecting the position of the European Union or the program management structures.

PARTNERS



Institut National Des Sciences
Et Technologies De La Mer



ASSOCIATES PARTNERS



CPMR
CRPM

