

Climate Change and Morphological Stability

Sousse Scale, Tunisia





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

Climate Change and Morphological Stability

Tunisian scale



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OVERVIEW

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REVIEW

Contributors

Nedra ASSES, PhD

📍 Higher Institute of Environmental Sciences and Technologies, Borj Cedria, Tunisia.

Ines CHNITI, PhD

📍 Higher Institute of Environmental Sciences and Technologies, Borj Cedria, Tunisia.

Reviewer

Adel OUERGHEMMI, Head of service; Financial Officer

📍 National Agency for Environment Protection Tunisia

Afef LAMINE, Technical framework; Technical Staff

📍 National Agency for Environment Protection Tunisia

Riadh HANNACHI, Head of Service; Administrative Officer

📍 National Agency for Environment Protection, Tunisia

Kholoud ATHIMEN, Engineer

📍 National Institute of Marine Sciences and Technologies, Tunisia

Supervisor

Ali SELMI, Principal Engineer

📍 National Agency for Environment Protection, Tunisia

Bechir BEJAOU, PhD

📍 National Institute of Marine Sciences and Technologies, Tunisia

LAYOUT

Khouloud ATHIMEN, Engineer,

📍 National Institute of Marine Sciences and Technologies, Tunisia

Ines CHNITI, PhD

📍 Higher Institute of Environmental Sciences and Technologies, Borj Cedria, Tunisia

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List of abbreviations

ANPE: National Agency for Environment Protection
APAL: Coastal Protection and Planning Agency
CRDA: Regional Commissariat for Agricultural Development
DPM: Maritime public domain
INM: National Institute of Meteorology
INP: National Patrimony Institute
INS: National Institute of Statistics
ONAS: National Sanitation Office
ONTT: Tunisian National Tourist Office
OTEDD: Tunisian Observatory of Environment and Sustainable Development
PDUI: Integrated Urban Development PROJECT
PNUD: United Nations Development Program

Abstract

Sousse's coastal areas have long been notable for their natural beauty, landscape diversity, the richness enhanced by the coastal and marine fauna and flora, rich cultural history, and diverse archeological heritage, all of these attract tourists from around the world.

However, the coastal morphodynamic processes, exacerbated by climate change, have introduced several challenges to the stability and sustainability of these tourism areas. Erosion, sedimentation, and sea-level rise are among the critical factors affecting the morphological integrity of Sousse's coastal areas. Other anthropological factors that have an impact include overpopulation, traffic congestion, rapid urbanization, and uncontrolled coastal development, as well as a traumatizing tourism development and the discharge of polluted waste water in the sea. The effects of degradation are more obvious as urbanization spreads into naturally occurring regions, which results in the erosion of dunes and the widening of beaches. This erosion poses a threat not only to homes but also to the environment. In fact, in places, the coast line recedes on average by more than 2 m per year, and dwellings that are currently subject to the front of the waves will risk being in the open sea if a solution is not found as soon as possible. Some of them are already there, others are partly destroyed.

While tourism has brought economic benefits, it has also strained resources and raised environmental concerns. Sustainable development and robust strategies are imperative to address these challenges and ensure the long-term viability of Sousse as a thriving coastal destination.

I. Introduction

The purpose of this report is to investigate how climate change has affected the morphology of the Sousse coastal tourist region. In a worldwide setting characterised by rising environmental challenges, it is critical to appreciate the specific implications of climate change on coastal regions, particularly those largely reliant on tourism.

Sousse, which is located on the east coast of Tunisia, is a popular tourist resort that draws a sizable number of domestic and foreign visitors each year. The area benefits from a pleasant climate, gorgeous beaches, a rich cultural history, and a well-developed tourism infrastructure.

However, global warming is becoming increasingly visible on this area, causing several severe repercussions on the coastal ecology and natural resources. These changes can be seen in the rising sea level, an increase in the frequency and intensity of storms, ongoing erosion of the coast, and other extreme climate phenomena. These realities do not escape the Sousse coastal tourist area.

The effects of climate change on the morphology of the Sousse tourism area's coastal area are significant on a number of levels. First off, coastal erosion and beach erosion may result in a reduction in the size of the resort areas, which will have an impact on the area's tourism industry.

In order to develop effective adaptation and mitigation strategies, it is crucial to thoroughly analyze how climate change has affected the morphology of the Sousse coastal tourist area.

A complex relationship exists between coastal development, urban expansion, and the various sorts of tourism activities that take place along the coast. Unplanned urbanization and the concentration of tourism infrastructure in vulnerable areas may have a significant impact on the overall morphological stability of Sousse's coastal regions.

This report will analyze the various facets of this impact, including rising sea levels, coastal erosion, salinization of soil and groundwater, and storm-related risks. There will also be recommendations made to support the long-term management of the tourist zone.

According to the TDRs, the goal of this deliverable is to:

- Highlight the different challenges to the morphological stability of tourist destinations in the Sousse region
- To provide an overview of the morphology of the area.
- To describe the phenomena of littorization and urbanization, and its impacts on the different forms of tourist activities in Sousse.

II. State of the coast of Sousse

II.1. Study area

The study area is located in the Tunisian Sahel, on the east coast of Tunisia. It occupies a strategic location on the edge of the Mediterranean Sea (Figure 1). Sousse governorate covers an area of 2308 Km². It runs along the coast of the Sahel from northeast to southwest, between latitudes 35°44' and 36°13' North and between longitudes 10°11' and 10°41' West (Boussema, et al 2023). It is limited to the north by the delegation of Enfidha and to the south by the delegation of Sidi Abdelhamid.

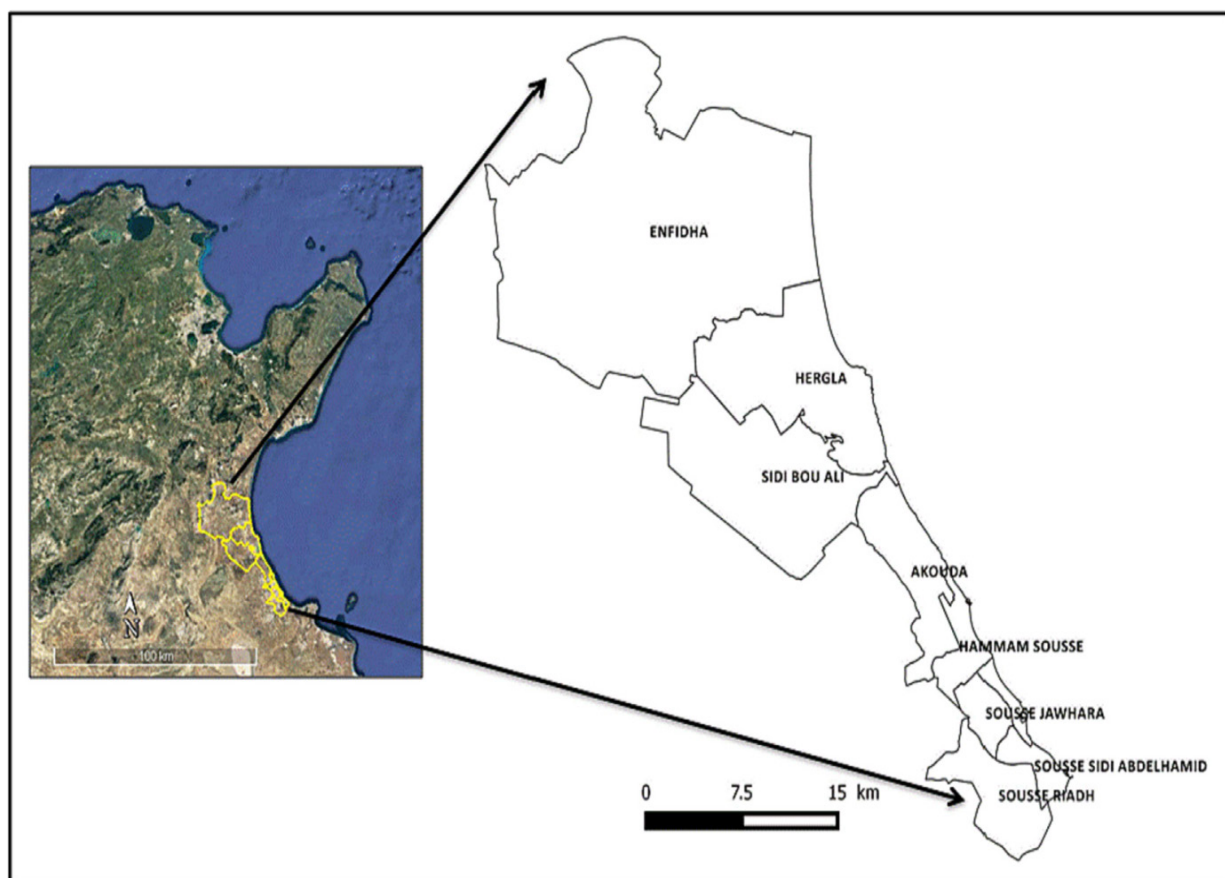
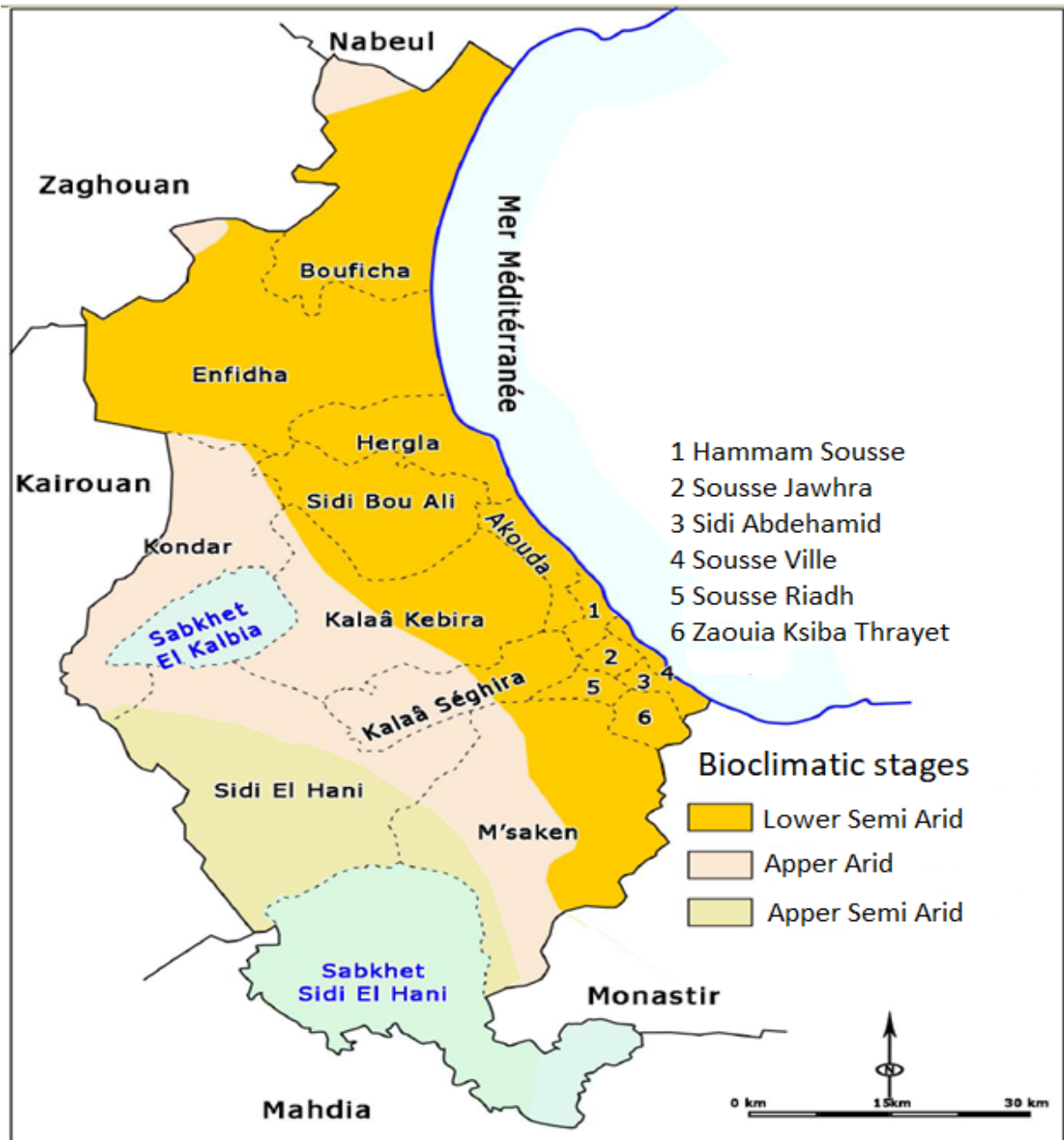


Figure 1. Localization map of the study area (Boussema, et al 2023)

The region of Sousse is characterized by a Mediterranean climate, belonging to the lower semi-arid bioclimatic stage of the lower steppes of the north (Figure 2).



Source CRDA Sousse 2019

Figure 2. Bioclimatic Stages of the governorate of Sousse

The general average rainfall in Sousse region calculated for the period between 2007 and 2017 is in the order of 258.5 mm (Table 1) and the annual average temperature is in the order of 18.6°C (Table 2). The region of Sousse is known by the diversity of its landscapes: forest, coastline, rural, urban, industrial, and natural, but strongly linked to the variation of the environments that make up it.

Table 1. Distribution of rainfall and rainy days in the governorate of Sousse

	Sep	Oct	Nov	Dec	Jan	Fev	Mar	Avr	May	Jun	Jul	Aug	Total
Quantities (mm)	40.6	50	33.7	40.2	37.4	34.6	29.5	26.8	16.6	7	1.5	7	324.9
Number of days	5	7	9	12	12	11	9	7	6	3	1	1	83

Source : INM 2018

Table 2. Characteristics of Sousse governorate temperatures

	Sep	Oct	Nov	Dec	Jan	Fev	Mar	Avr	May	Jun	Jul	Aug	Mean
Average	24.7	21	16.3	12.7	11.5	12.3	13.8	16.8	19.1	22.7	25.9	26.6	18.6
UpperAverage	29.2	25.6	21	17	15.9	16.8	18.5	20.7	23.5	17.1	33.7	31.4	23.1
Loweraverage	20.3	16.4	11.7	8.3	7	7.7	9.1	11.8	14.8	18.4	21.2	21.8	14.4

Source INM 2018

II.2. Coastal characteristics and morphological evolution tendencies

II.2.1. Cotes of the Sousse region

The coastline of the Sousse Governorate stretches for around 85 kilometers along its length and is dominated by its sandy beaches. The beach measures 100 meters to the north of the governorate and 20 meters to the south. In the shores of Sousse, there are two main types of forms: low rocky coasts and sandy beaches (PDUI, 2020).

• Sandy beaches.

The Grand Sousse coast is a section of a rather homogeneous segment of coast that extends from Kelibia in the north to the septennial reaches of the Monastir peninsula. This section includes the coastline of the Cap Bon as well as the entirety of the Hammamet Golf and its extension south. Overall, there are very low mountains that are distinguished by large, uninterrupted beaches that stretch from Hammamet to Hergla and from Chott Meriem to Skanes (with the exception of the port of Sousse and the infrastructure that is located at its mountainsides (PDUI, 2020).

• Rocky coastline and cliffs

They are most notable in Hergla (Figure 3), though. The hills on which the agglomeration is growing directly border the river there. This mechanism has favored the development of a morphology of cliff-tipped rocky coasts. These are not particularly tall (3-5 m to a maximum of 15 m), but because of how they contrast with the low ground that adjoins them, they distinguish the landscape. It is also noteworthy that there are some thin marine deposits made mostly of gravel, sand, and marine shells, particularly at the base of the talus that dominates the coastal plain at El Kantaoui (APAL/PNUD, 2012).



Figure 3. Rocky coastline in Hergla (APAL/PNUD, 2012)

II.2.2. Active sediment Dynamics

The distribution of wave energy in the area as well as the general water circulation in the Gulf of Hammamet (density gradient) are all factors that must be taken into account for the movement of sediments.

The primary cause of sediment movement in this coastal zone is typically attributed to the misalignment of the angle of wave incidence with respect to the coastline during deferral. The radiation from the vague generates special circulation that is characterized by a longitudinal sediment transport that is either directed north-south or south-north depending on obliquity.

• Between Hammamet and Sousse's harbor

The climate is very sensibly North-South. A primary coastal deviate in the north-south direction and a secondary deviate in the south-north direction are produced by the strong obliquity between the main houles and the coast. These houles guarantee a significant sand passage because of their strong obliquity relative to the coast (Brahim, 2022).

• Between Sousse's harbor and Monastir

The situation is a little more complicated. The North-East houses that encroach the coast between the port of Sousse and the northwestern portion of the Dkhila Bay, which is toward the North-West and South-East, are frontal, making passage impossible. However, the strong North-West to North-West obliquity caused a sever transit to the south. The houses in the East/Northeast to the Southeast create a transit to the north. A sediment transit toward the south of between 10,000 and 20,000 m³ each year is the result in this sector (Brahim, 2022).

II.2.3. Alarming signs of erosion

By superimposing the various coastal traits from various missions several works were able to identify the area most vulnerable to and adversely affected by natural degradation, particularly erosion. The following section will go into detail about the four most significant and naturally degrading areas.

- **Grand Sousse**

The Sousse coastline is distinguished by the presence of large, vulnerable beaches affected by the coast-reclining phenomenon. The degradation of vegetation and aquatic ecosystems, as well as the erosion of beaches, have been brought on by human activities such as pond construction and drainage system design. Some beaches, including those in Hammam-Sousse and Sidi Abdelhamid in Sousse, are currently being damaged. The central beaches are overused, similar to Boujaafar beaches in Sousse, far above their estimated maximum capacity of 4m² for person (Regaya & Haouala, 2018). The general condition of the beaches is deteriorated by the discharge of used water and solid waste into the ocean through the ditches and waterways that flow into the sea such as Benetton cloths manufactory and Gloulou Concrete Manufacturing that dump, respectively more than 800 m³ and 20 m³ of used wastewater /day in Oued Hamdoun then into the sea.

The effects of degradation are more obvious as urbanization spreads into naturally occurring regions, which results in the erosion of dunes and the widening of beaches. Port improvements have also accelerated this degradation, benefiting tourism's increased use of the seafront. Hydrological improvements on the main rivers have decreased the amount of runoff that reaches the sea, resulting in a sediment deficit and significant erosion of the beaches. The following chart illustrates the Grand Sousse beaches' severe degradation through comparison and superposition (Figure 4).

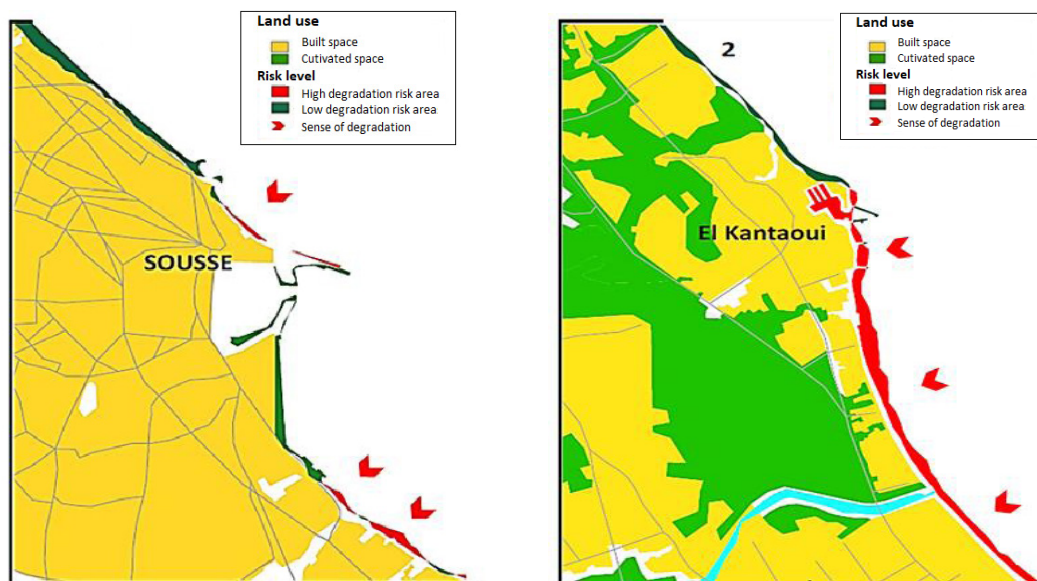


Figure 4. Evolution of the coastline's shape in the Grand Sousse between 1883 and 2015 (Regaya & Haouala, 2018)

Very pronounced erosion phenomena on the coast of Sid Abdelhamid, between 1935 and 1955 (Figure 5), attests to the role played by the port in the under-saturation of the drift and therefore in the activation of erosion on the coast with a faster rate. strong recorded between (1986-2018).

Between the Commercial Port of Sousse and that of the thermal power plant, the evolution of the coastline from 1962 to 2010 varies depending on the location and the developments that have been carried out there (Souayed, et al., 2011). To the south of the commercial and fishing port the coast has evolved in time and space as a result of various human interventions, and was marked by a period of relative stability from 1963 to 1986, which has since been followed by a retreat of the coastline of more than 2 m per year in some places .

To the north of Oued Hamdoun the coasteline is advancing by roughly 2 to 3 m each year, owing to the abundant spillage of cooling water of more than 1,680,100 m³ / day; this section finishes at the jetty of the thermal power plant's port (Figure 6).

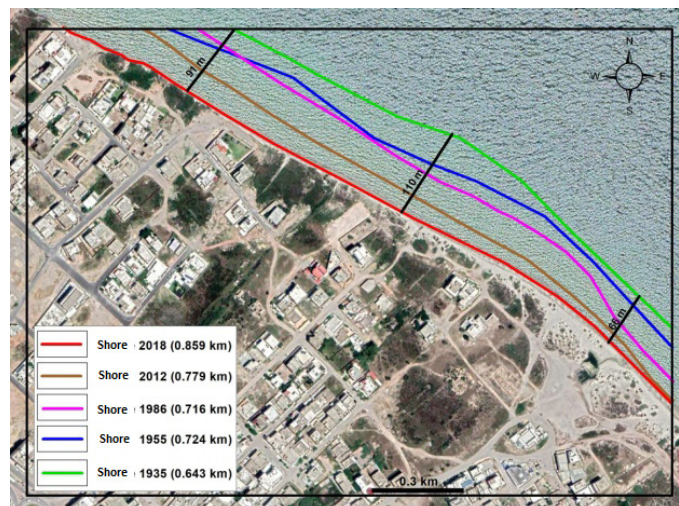


Figure 5. State of the Sidi Abdelhamid coastline between 1935 and 2018 (PDUI,2020)

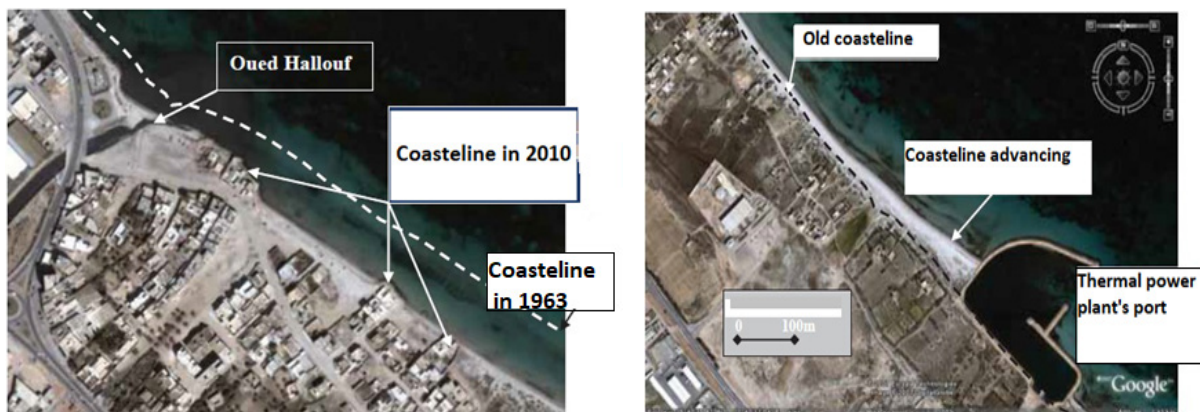


Figure 6. Evolution of the coastline between the fishing port and the port of the thermal power plant. (from Google Earth satellite image, 2010).

• Enfidha Hergla

The ports built at the end of the previous century at the north and south ends of the bottom of the Hammamet Golf caused the disruption of the longitudinal sediment transit and a very serious erosion problem in the Hergla Zone. The southern Hergla fishing port built in 1985. The issues have existed since the project's inception, with a frequent enlargement of the bassin to the south and a significant maritime erosion to the north. The Yasmine El Hammamet port of pleasure built between 1996 and 2001 in the north as part of the development of the tourism area caused a disruption in the sedimentary flow with an encroachment to the north and a decroachment to the south.

Following cartographic work on this section of the coastline (Figure 7), stability was found on the beach between the Roman pontoon and Selloum. There are signs of progressing fattening between Asset Selloum and Borj El Medfoun. A stable relationship between Borj El Medfoun and Oued Ammouch (seen in green on the following card) and a few signs of regression. Strong erosion and regressive movements between the Hergla city and the El Medfoun forest. Observable berg-sapping phenomena are those at Oued Chogaf and Oued EsSed, for instance. The following map depicts the evolution of the Hergla region's coastline (Regaya & Haouala, 2018)

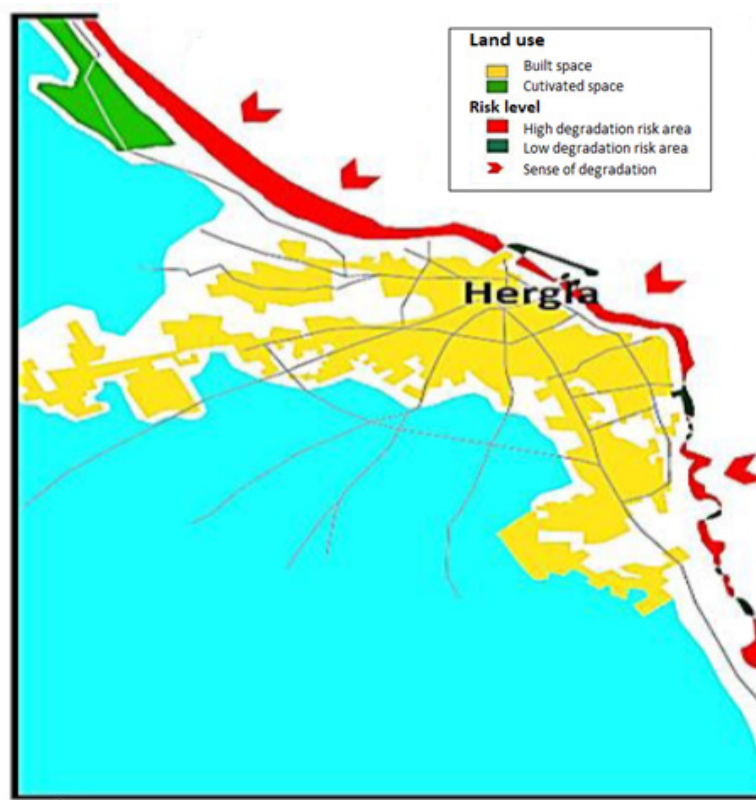


Figure 7. Hergla coast's change between 1883 and 2015 (Regaya & Haouala, 2018).

II.3. Various Costal Ecosystems harmed by climate change

The coastal ecosystem in Sousse region is marked by natural sites characterized by the striking singularity of their composition and their richness enhanced by the coastal and marine fauna and flora (Figure 7).

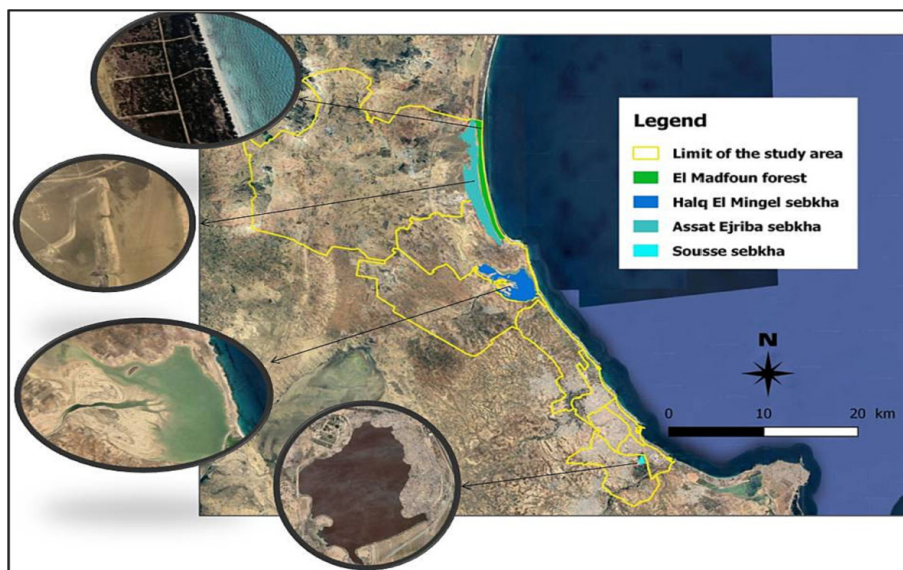


Figure 7. Distribution map of ecological sites in the Sousse region (Google Earth, 2022)

II.3.1. El Madfoun forest

The forest extends over 21 km along the coast, between Hergla and Salloum, with a variable width of 50 to 500 m, and occupies an area of about 450 ha. This forest is one of the rare coastal forests in the country (Figure 8) and constitutes a regional lung, a reserve of fauna and flora, a fixative element of the coastal dunes, and a distributor of a microclimate by its role of protecting the winds and through its influence on various climatic processes (Boussema, et al 2023).



Figure 8. Madfoun Forest (Atlas, 2021)

The forest canopy is vulnerable to degradation as a result of road trampling, urban expansion, particularly anarchic expansion, as well as damage and fires caused by riverine or passengers. For example, four fires burned over 0.3 hectares in 2018. The “Madfoun” forest is deteriorating and is on the verge of collapse. Similarly, the beach has been reduced (almost half of it has been lost between 2002 and 2019) (Figure 9).



Figure 9. Evolution of the perimeter of the “Madfoun” forest between 2002 and 2019 (PDUI 2020)

II.3.2. Wetlands aggressed

The governorate of Sousse includes several humid areas made up of littoral “sebkhas” such as Sebkhat Assat Jriba, Sebkhat Sidi Khelifa, sabkhet Sousse and interior sebkhas such as Sebkhat Sidi El Hani, Sebkhat Echrita, and Sebkhat Halk El Menjel.

These humid zones in the Grand Sousse region play a vital role in the conservation of ecosystems. They represent a potentially profitable opportunity for ecotourism. However, these areas frequently become garbage dumps, especially if they share habitation areas.

The study area’s northern Sebkhat Halk El Menzel and Fôret ElMedfoun ecoregion appears to be one of Tunisia’s most significant. Moreover, Halq El Mingel sebkha is subject to severe pollution, caused by the ONAS station and Sidi Bouali dairy plant

Sousse sebkha is located in the south of Sousse city, and occupies an area of 62 ha. It is well located in an urban environment and close to the industrial area of Sidi Abdelhamid. It is a very fragile ecosystem which has become increasingly degraded nevertheless, this ecosystem still represents an ecological potential that must be developed in order to restore and preserve the environmental quality of this area and restore the natural functions of the sebkha (Atlas, 2021; Boussema, et al 2023).

II.4. Diversified archaeological heritage

The governorate of Sousse is one of Tunisia's richest regions in terms of ancient structures dating back to antiquity. About 30 monuments that the National Patrimony Institute (NPI) has designated as part of the National Patrimony are spread across the Sousse Governorate (Atlas, 2021)

Navigators from Tyr in south-Liban decide to establish a trade hub on its navigable river in the Xe century before Jésus-Christ, promising it an exceptional destination. Hadramaout, a vibrant and prosperous maritime city, sees the light of day quickly, marking the beginning of a turbulent but colorful historical course. Mangled by all the horrors of the protracted war

between Rome and Carthage during the infamous Punic Wars, the city begins to flourish commercially again in the first century of the Christian era under the name of Hadrumetum.

Great progress occurred in many spheres, and as a result, it encompasses huge public and private structures like spas, temples, theaters, and opulent homes.



Roman Temple and Nymphaeum



Triumphal Arch

Figure 10. Archeological structures at Sidi Khlifa (Atlas, 2021)

Captured by Arab cavalry in 665, it was brought back to life in the 8th century with a new name, "Sousse". In the 19th century, it experienced a new age of gold for the first time. As the new capital of the country and the summer residence of the rulers of Aghlabide, Kairouan once again transformed itself into a vast cosmopolitan urban center, losing many monuments of rare splendor

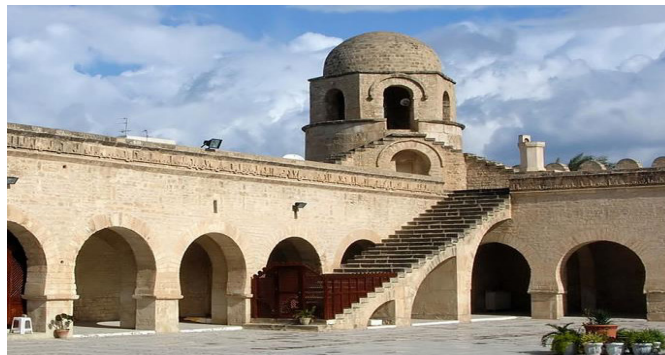


Figure 11. Great Mosque Sousse Médina (Atlas,2021)

The presence of archeological remnants from “romaine farms” on the beaches of Enfidha and, more specifically, Borj El Madfoun, defines the coastal region. These cultural assets have not been safeguarded up to this point, and they are vulnerable to a variety of erosion factors that speed up both the degradation of this heritage and the deterioration of the coast.

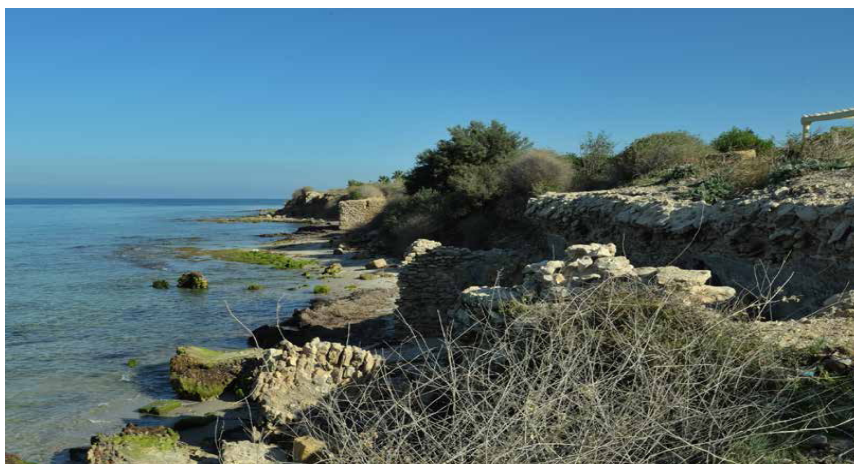


Figure 12. Archaeological flaise in the Hergla area

The Roman cities on the Hergla site really make up the basement level of historic homes, of which only a few abandoned remnants remain. The figure displays a photograph that spans the years from 1991 and 2015. She displays the speed of the falaise’s collapse, allowing the viewer to understand the pace of the exhumation of the city and the amount of archaeological material that was gradually exposed to the direct action of the waves (Oueslati, 2021)

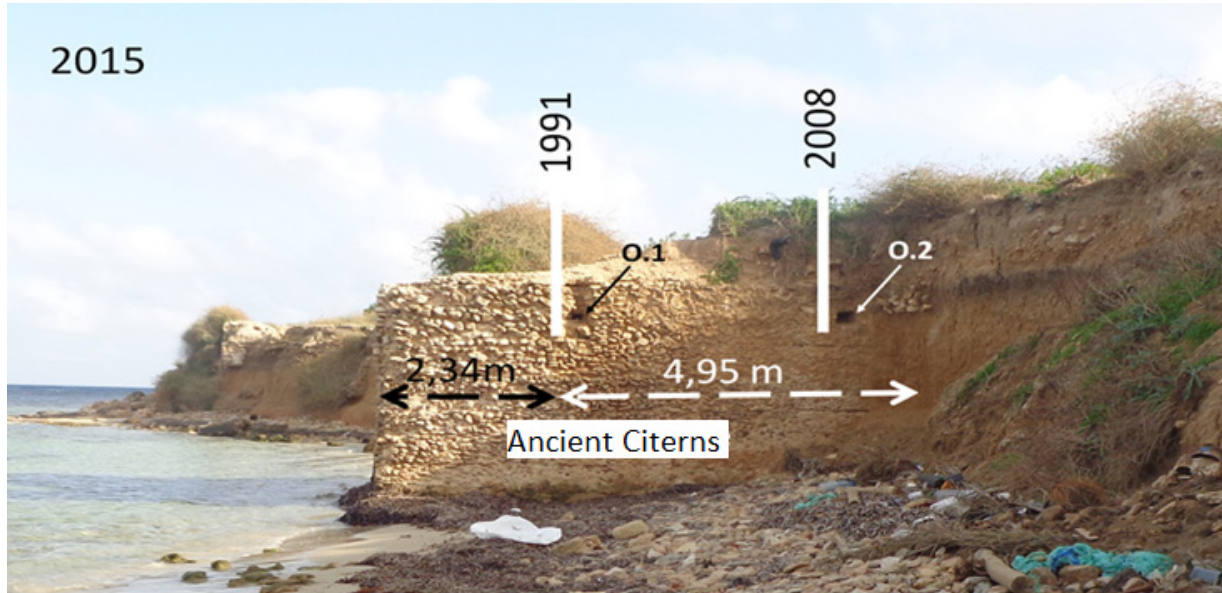


Figure 13. Roman cities with ancient citerns in Hergla

III. CONSTRAINTS AND ANTHROPOIC PRESSURES

Constraints and Anthropogenic Pressures in Sousse cover both the analysis of constraints and the effects of people on the city of Sousse. When referring to constraints in Sousse, it means a variety of elements that could restrict or limit particular facets of the city's growth or operation. The expansion and planning of the city may be hampered by social, economic, or regulatory reasons, as well as by natural conditions like geography, climate, or the availability of resources.

III.1. Overcrowding and congestion in Sousse

Congestion and overcrowding are frequent issues in many places, including Sousse. Sousse has a high population density and an increasing need for infrastructure and services as a result of being a well-liked tourist resort. Congestion and overcrowding-related problems may result from this. Here are some important things to think about:

- **Population Density:** Sousse has a high tourist population and has seen population expansion over time. Urban locations can become crowded due to the concentration of people, especially during the busiest travel seasons.
- **Traffic Jams:** Sousse may experience traffic jams due to a surge in both the population and the number of vehicles.

Between 1994 and 2014, the population of the Sousse Governorate increased from 433,709 inhabitants to 544,413 in 2004 and reached 674,818 in 2014. In 2017, this demographic growth continued, recording 721,376 inhabitants. The growth rate recorded between 1994 and 2004 was 2.3%. Between 2004 and 2014, it dropped slightly to 2.17%. But the growth rates recorded over the past two decades are indicative of the high degree of attractiveness of the subsea governorate. Its demographic weight evolved remarkably between 1994 and 2014, which testifies to its importance in regional and national urban armor.

Table 3. Demographic weight of the Sousse Governorate/Centre-Est Region and the national territory

	1994	2004	2014	2019*
Population of the Governorate of Sousse	433,709	544,413	674,818	721,376
Population of the Eastern Central Region	1,867,041	2,233,112	2,704,000	2,816,154
Number of inhabitants of the territory	8,785,364	9,910,872	10,982,476	11,818,385
Demographic Weight/Centre East Region	23.23	24.38	24.95	27.07
Demographic and National Weight	4.93	5.5	6.14	6.44

Source: INS-1994-2004-2014-* 2019 forecasts

Between 1994 and 2004, the number of inhabitants increased in 14 delegations and decreased in the two delegations of Sousse - Medina and Sousse-Jawhara, following the modification of the administrative division of the governorate and the creation of a new delegation from Sousse Sidi - Abdelhamid. In 2014, another administrative cutting was carried out and gave rise to a new delegation: Zaouiet Thrayett. The Sousse Governorate now has 16 delegations and the change in its administrative division illustrates the importance of its demographic dynamics.

Table 4. Population evolution between 1994-2004 and 2014 by delegation

	1994	2004	2014	2019*
Sousse ville	31,469	29,680	35,288	37,909
Sousse Riadh	42,697	65,333	64,532	74,307
Sousse Jawhara	74,390	62,663	86,517	99,877
Sidi Abdelhamid	-	46,257	52,787	55,450
Hammam-Sousse	26,531	36,685	42,691	46,770
Akouda	20,080	25,717	34,494	39,383
Kalaâ Kebira	44,890	51,196	59,132	62,496
Sidi Bou Ali	15,036	17,606	19,543	20,470
Hergla	6,909	7,913	9,343	9,924
Enfidha	37,964	43,426	49,335	51,484
Bouficha	19,675	23,581	26,760	27,577
Kondar	10,020	11,636	13,565	14,176
Sidi el Hani	10,873	11,614	13,505	14,109
M'Saken	72,932	85,380	97,225	102,452
Kalaâ Séghira	20,243	27,726	37,797	43,268
Zaouia/Ksiba et Thrayet	-	-	32,304	41,132
Total	433,709	544,413	674,818	721,376

Source: INS-1994-2004-2014-* 2019 forecasts

III.2. Rapid and uncontrolled urbanization and expansion to the periphery of Sousse

In the 2004, the population density of the Sousse Governorate was estimated at 243.5 inhabitants /km² (Figure 14) In 2014, it increased to 301.82 inhabitants /km². Between 2004 and 2014, the density of the governorate remained significant compared to the national average (70 inhabitants /km²). But this regional average hides the disparities that emerge if the territory of the governorate is divided into 4 sets:

- The first set includes delegations with a large density of more than 3,400 inhabitants/km² between 2004 and 2014; namely: Sousse Ville, Sousse Riadh, Sousse Jawhara and Sousse Sidi Abdelhamid

- The second set includes the delegations of Hammam-Sousse, and Akouda, which recorded more than 1000 inhabitants/km². In 2014, the density of the Hammam - Sousse delegation is 2000 inhabitants/km².
- The third set concerns the delegations that registered between 100 and 400 inhabitants/km², namely: Kalaâ Kébira, Sidi Bou - Ali, Enfidha, Bouficha, M'Saken and Kalaâ - Séghira.
- Finally, the fourth set consists of delegations with a density of less than 100 inhabitants/km². These are the delegations of Hergla, Kondar and Sidi El-Hani.

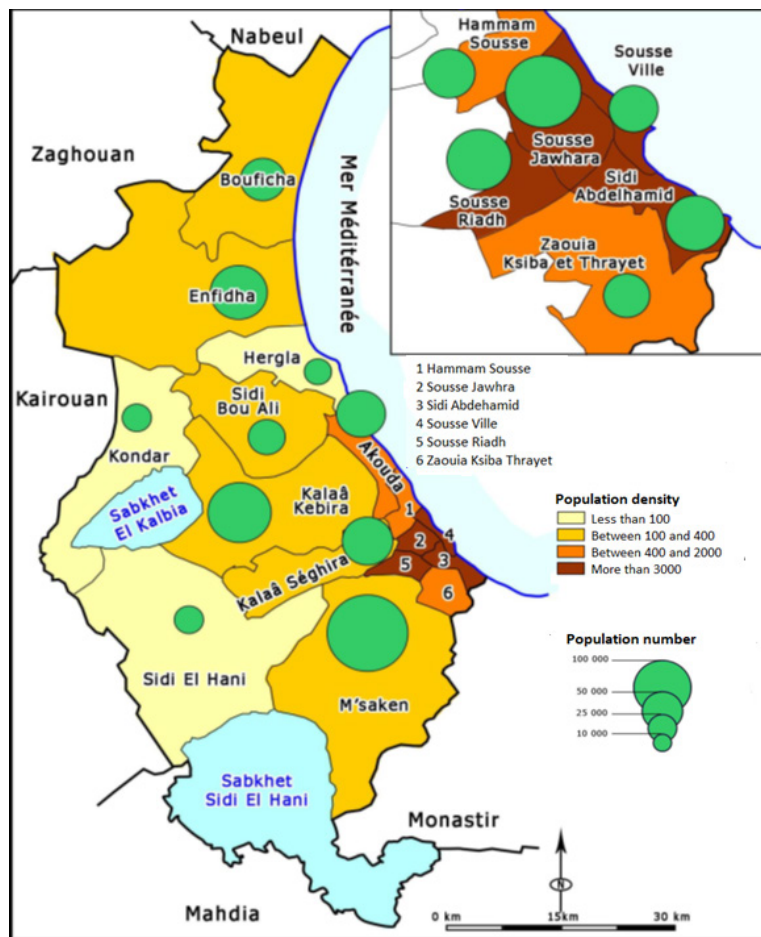


Figure 14. Population Density Map in Sousse 2014
(Atlas, 2021)

Urban deployment is a new form of urbanization, consuming more land per capita and increasingly diverging from the compact city model, referring to urbanization in the form of town houses, adjacent buildings and grouped habitats whose growth occurred naturally in continuity with previous urbanisations.

Determining the space growth of the Grand Sousse goes through the analysis of the available air photos from different periods.

- Urban displacement occurs by contagion. Progressive changes in space are observed in direct contact with the main urban nuclei. The distance from the center is a determining element of this surface dynamic.
- Emergence of a new spatial configuration, in the form of agglomeration or poles, which concentrates a demographic and economic potential. The assignment of a new administrative status to these agglomerations is seen as a catalyst that provokes a repositioning of these agglomerations in the urban hierarchy.
- The changes caused by urban expansion can be observed mainly by the evolution of the dynamics of the agglomerations (emergence of new agglomerations, new hierarchization of agglomerations, new density, new equipment, employment pool, etc.).

The urban expansion was made both to the North-West and South-West. At first this only concerned the cities of Sousse, Akouda and Hammam Sousse but from the independence the urban spot spread in a remarkable way. The density of the population of the Grand Sousse territory is inversely proportional to the distance from the heart of the area. Thus, the further away from the centre of Sousse, the less density is important (Bel Fekih Bousemma et al., 2021).

Similarly, this urban expansion is a marked fact of the urbanization of the region for several decades. The urban space is strongly marked by the important concentration of habitat and population on a long strip of coast dominated by the imposing regional metropolis of Sousse, and an extension to the inside that clamps on the road network.

The expansion of the peripheral cities has taken place in such a way that cities such as Hammam Sousse, Akouda and Zaouiet Sousse which are former agricultural villages that were previously considered to be distinct spatial entities of Sousse city, are now increasingly perceived as suburbs, especially as the spaces separating them from the city are reduced under the effect of the creation of some new settlements such as the two Cities of Ezzouhour and Riyadh.

At the level of the Grand Sousse, the population density of the territory is inversely proportional to the distance from the heart of the area. Thus, the further away from the centre of Sousse, the less important the density (Atlas, 2021).

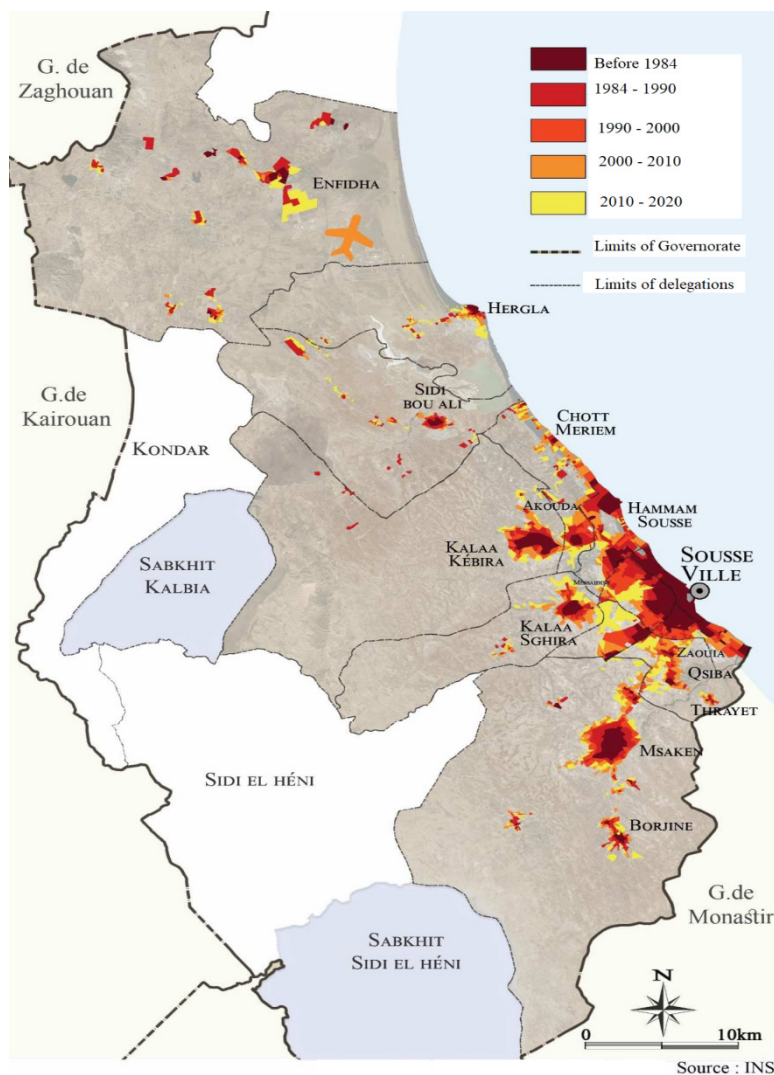


Figure 15. Evolution of urban deployment in the Grand Sousse since 1984 (Atlas, 2021)

III.3. A traumatic tourism development

The city of Sousse has a rich historical background that draws visitors from all over the world. There are about 130 hotels in the city that are solely focused on tourism. During the peak season, the tourism industry generates close to 20,000 employments annually and has erected three sizable resorts.

Between 2016 and 2017, employment and welfare indicators in the Sousse Governorate improved, following efforts to develop the sector. In 2017, the number of incoming tourists amounted to approximately 941,276; or 17% of the total number of tourists (5,518,418 tourists). The number of nights was estimated at 4,232,974; or 19.2% of the nights recorded nationwide.

The average stay reached 4.5 nights, knowing that the tourist area of Chott Mariem - Hergla recorded the highest average (6.9 nights). The employment rate remains low, although it improved from 29.3% in 2016 to 37.5% in 2017(ONTT, 2020).

Table 5. Numbers of night's tourism in Sousse in 2017

Month	Sousse		National	Month	Sousse		National
	Number	%	Number		Number	%	Number
January	121,334	16.1	753,394	August	1,030,462	21	4,901,401
February	91,669	15.6	588,077	September	644,321	20.5	3,139,237
March	155,120	17.1	906,044	October	415,192	20.3	2,048,756
April	163,099	15	1,084,499	November	152,362	16.7	910,095
May	242,521	17.6	1,380,612	December	183,177	18.7	979,411
June	307,706	17.9	1,715,538	Total	4,232,974	19.2	22,042,523
July	726,011	20	3,635,459	Source: National Tourism Office of Tunisia(2017)			

The number of tourists who visited the Sousse-El Kantaoui tourist region rose by 98% in 2022, compared to the same period in 2021. Sousse tops the list of Tunisian tourist destinations with 76% of visitors in 2019 (reference year). The number of tourists in 2022, who had visited Sousse in December 20-31 had been up by 0.5% to 50,988 thousand, against 50,716 thousand in 2019. Hotels in Sousse City and El Kantaoui had accommodated 995,234 tourists in 2022, against 502,022 in 2021.

The number of Algerian tourists edged up by 1,000% compared to 2021, according to the Local Tourism Authority.

Hotels in Sousse El Kantaoui accommodated 127,902 thousand Algerian tourists in 2022, including 14,735 thousand on the new year's eve. The traditional markets also made a comeback, such as the German market as it posted a 692% rise in the number of tourists to 47,015 thousand, the UK market (up 1,000% to 48,837 thousands) and the French market (+386% to 54,157 thousands). All the indicators mentioned continue to increase, which further aggravates the fragility of the region environment (ONTT, 2020).

III.4. Polluted wastewater discharged into the sea

In the Grand Sousse, the pollution-generating industries are quite diverse, ranging mainly from the textile sector to the clothing, agro-food, mechanical and metallurgical sectors. The majority of industries are concentrated at the level of the industrial zone of Sidi Abdelhamid, the rest are scattered in smaller industrial zones distributed between the different locations of the Grand Sousse.

These industries discharge polluting waste of several types, which conjugate with those of domestic origin. The degree of their impact on the degradation of the natural environment varies from one area to another. However, the coastal area of Sousse Sud and its marine environment appear to be the most affected by these polluting discharges.

For example, high and continuous concentrations of germs are observed at Sidi Abdelhamid Beach and most of the time at Gaied Souassi Beach. This pollution can largely be explained by the following factors:

- The discharge of raw industrial wastewater, either directly into the sea through channels and discharges, or through the different waves leading to the sea, releases essentially organic pollution. It causes water pollution and accelerates eutrophization of the ecosystem.
- The location of wastewater discharges from purification stations. During peak periods, these stations work at saturation and discharge volumes of untreated water. In addition, these stations need regular shut-off periods for their maintenance.
- Uncontrolled evacuation of primary processing and packaging of fish at the level of the fishing port. Waste from these activities is thrown directly into the sea in its raw form.

The protection works set up at the level of the Gaied Souassi beach cause water stagnation and promotes the intense development of algae colonies, a source of pollution and bad smell.

III.5. A coastal area affected by aquaculture activities

The fisheries sector accounts for 4.5% of domestic fish production and provides more than 1,000 jobs. But, they are also potential sources of water, chemical and solid pollution. The Grand Sousse region, on the side of Hergla, contains two aquaculture sites, on land basins (in operation since 1998 on 80 ha) and submersible floating cages (in activity since 2006) (MEDD/PNUD, 2007).

Aquaculture on land or at sea creates pollution. The fish diet contains diverse food and other products, which dilute in the water and can contaminate it, with effects on human health and the cleanliness of the environment.

Intensive aquaculture, as practiced today, is considered a potential source of pollution. Close interactions between the livestock environment and the ecosystem that houses the cages increase the risks of pollution. This pollution can take several forms: organic, chemical, bacteriological, genetic and etc. Pollutant streams can infect the local environment but also spread on large scales, away from livestock sites. The legislation in Tunisia, like elsewhere, is not yet adapted to this type of problem. “The fastest way to reduce pollution from aquaculture seems to be, for now, to reduce the amount of food.

They are spilled by increasing the energy value of them (which will imitate the amount of substances in suspension), and replace some of the proteins with lipids. However, the implementation of this type of food requires high technical skill.

As a result, in recent years, seafarers exercising in the port of Hergla have expressed their dissatisfaction with the competition of aquaculture companies that monopolize significant sea surfaces, which has caused a regression of their shares of fish resources in the region. In this case, they complain about the lack of control for the fight against ever-increasing environmental pollution due to the dumping of plastic waste into the sea, after feeding the grown fish.

Aquaculture has very different impacts on the natural environment, depending on the way animals are fed. In all cases, there is a rejection of nitrogen and phosphorus that can lead to eutrophication. In this case, the Hergla aquaculture farm uses the Sebkha of Halk El Menjel as a landfill for its waste. According to the same source, the farm rejects the sebkha fish waste and disinfectant products, antibiotics against parasites, steroids -to produce more females- and drugs and hormones to accelerate their growth.

IV. Vulnerability of hillsides to flooding

The erosion of the coast and especially the sandy coasts, which are the most fragile due to the high mobility of sediments, is a common phenomenon in the world. It is mainly due to a disruption of the hydro-sedimentary regime on the coast. This disturbance caused a shortage of sand, which began to manifest itself after the end of the postglacial transgression, and which was accentuated in contemporary times by anthropic pressures, in particular the construction of dams on the rivers, the installation of anarchic structures on the coasts and the realization of ports without impact studies founded for coastal evolution. The noticeable rise in sea level will likely aggravate the erosion of the beaches. As everywhere else in the world, the coasts of Tunisia are shrinking. Many of our beautiful beaches have ended up seeing their surfaces shrink; others are in an advanced erosion phase. This is the case with the north coast of Sousse's city.

IV.1. Sea level rise

Statistics from the intergovernmental panel on climate change (IPCC, 2013) show that between 1900 and 2000, there was an average global sea level rise of 1.7 millimeters per year. The trend is currently accelerating: from 1993 and 2003, the average rate was 3.1 mm/year, translating to an increase of 31 cm over a century. The coast of Tunisia, in this example that of grand Sousse, is expected to have seen an average rise in sea level of 30 to 50 cm by 2050. It would result in a 20–135 cm yearly rate of beach retreat, depending on the sites and beaches. At 0.50 m per century, sea levels are predicted to rise. Between 1:50 and 1:100 is the slope of the coastline profile. Accordingly, for the following century, the sea level rise will cause the coastline to be displaced 25 to 50 meters inland. In terms of sensitivity to anticipated sea level rise, the great Sousse region falls between a high and extremely high category.

IV.2. Vulnerability of the coastline to erosion

Erosion of sandy beaches constitutes a noticeable brake to the development of beach tourism in Sousse. The degraded coastal line, which extends from the fishing and trade port to the left bank of the Oued Hamdoun, accounts for 39% of the city's total coastline. This accentuates the frequentation of the tourist beach and the over-exploitation of the beach of Boujaâfar. With forecasts of sea level rise by 2100; the "coastal erosion" wave increasingly threatens the stability and extent of the beaches, which will further reduce the tourist accommodation capacity for swimming.

For a long time, erosion events have damaged the littoral. Beach erosion and dune regeneration are two isolated yet remarkable phenomena that affect the Sousse Bay. This littoral fragility, however, is an ongoing issue. As a result, unlike the more obvious erosional indicators at Boujaâfar and Hadrumète beaches, the city's "tourist" beach in the north has only slightly deteriorated. Throughout the southern littoral, extremely serious instability manifestations are found. The deterioration of the beaches has

considerably impeded the growth of balneotourism in Sousse. 39% of the city's total coastline is made up of the city's degraded coastal line, which extends from the port for trade and fishing to the left bank of the Oued Hamdoun. This raises the rate. The most obvious effect of climate change on the coast is the rise in sea level. In addition to the obvious physical effects of land loss, it also creates a number of concerns with coastal management, ecosystem adaptation, and socioeconomic issues.

Submersible areas or areas at risk of annexation by the sea are land at altitudes between 0 and 1 m or less than 1 m with a risk of erosion. However, these lands represent a good majority of the Soussian coastline. Most often, they correspond to coastal wetlands (lagoons, sebkhas, mouths of valleys, etc.), but also to various other coastal lowlands. The latter are frequently alluvial plains exploited in agriculture or occupied by built-up areas, in particular tourist buildings.

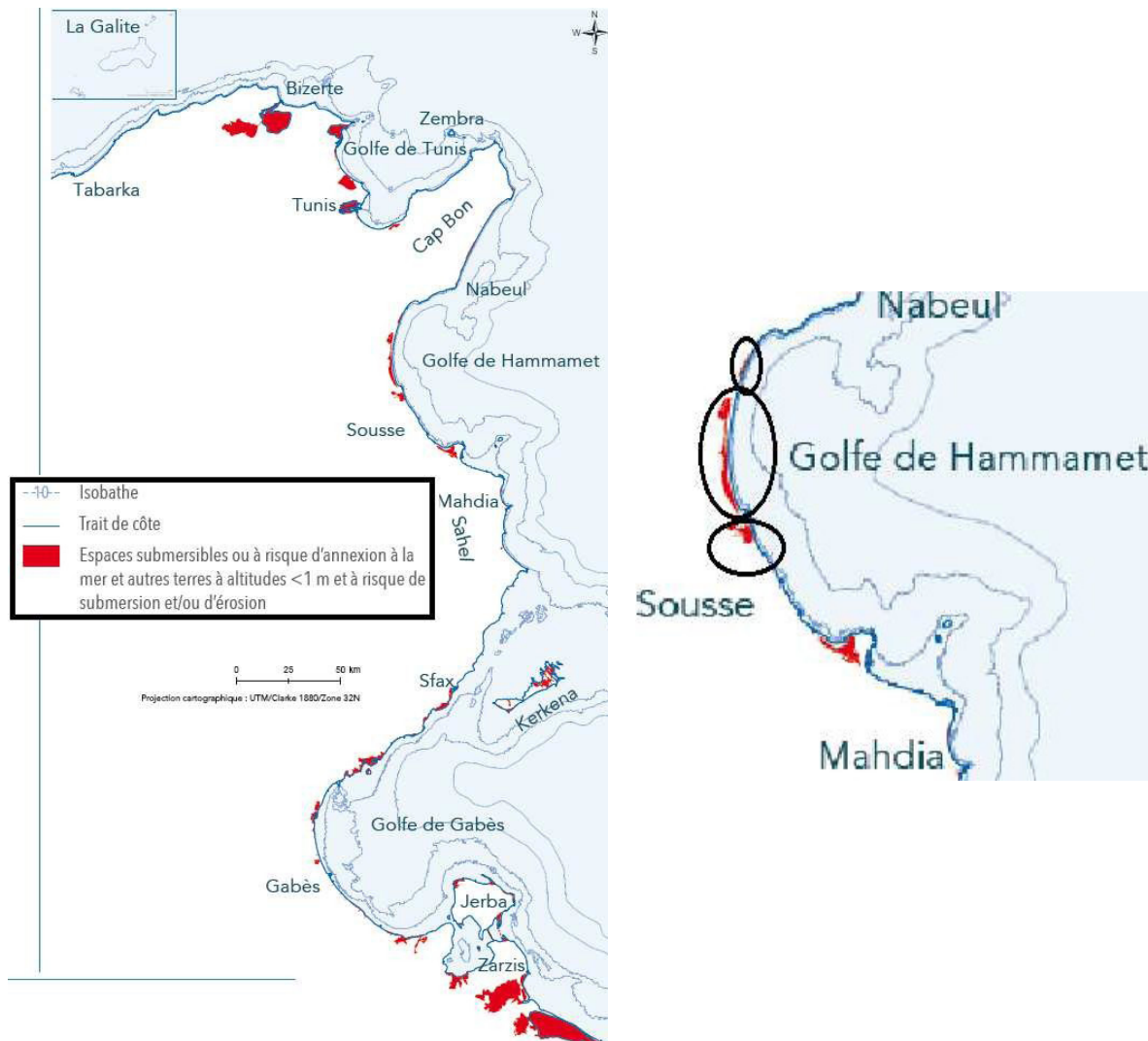


Figure 16. Submersible or areas at risk of annexation to the sea and other lands at altitudes < 1 m and at risk for submersion and/or erosion map

(APAL, 2015,)

From Hammamet south to Hergla, it can be considered that the entire coastline is in a fairly balanced situation. This is the case with the long remaining deserted beach that extends from Salloum to Hergla and more to Madfoun or it is bordered by a 30 border dune (PDUI, 2020).

From EL Kantaoui, going to Sousse, the erosion of the beach poses problems in a sector where tourist arrangements have been deployed. Even before the construction of the recreational port of El Kantaoui, this part of the coast was in decline as evidenced by the attack by the waves of blockhaus dating from the eve of World War II.

In addition, discharges of sewage into the Oued Hamdoun 500 m from its swamp, and hot water from the thermal power plant installed on the coast of Sidi Abdelhamid have led to the degradation of the posidonies and have amplified the erosion phenomenon along the Sidi Abdulhamid coastal swamp.

The sandy coast of Sousse-Monastir (East Tunisia), situated between the Commerce port of Sousse and Skanès-Monastir, has experienced since 1962 an important anthropological activity by the multiplication of hotel and road infrastructures, which hit the overseas, by the construction of the Commercial port of Sousse and the cooling basin of the coastal thermoelectric power plant of Sidi Abdelhamid. These arrangements weakened the sedimentary budget of the coast and deregulated the trade that itined with the areas that frame it, leading to more or less widespread erosion. The use of protective works (breezers and crashes, south of the commercial port) has only shifted the erosion further downward, in the direction of the coastal drift.

In fact, the maximum erosion is recorded between Hallouf and Sidi Abdelhamid and in the western sector of Dkhila Bay, where the coastline declines at an average rate, respectively 1.02 and 1.22 m/year, for the respective periods between 1925 and 1996 and from 1925 to 2001 (Figure 17). The extent of the erosion phenomenon in these two sectors is linked, on the one hand, to the intensification of urbanization and amenities, and on the other hand to the weak current river supply and the strong exposure of two coastal streams to the dominant winds in the northeastern sector. It is different in the area at the bottom of Dkhila Bay, where the shores are stable or in accretion, as they are still well fed in sediment by coastal drifts from adjacent sectors (PDUI, 2020).



Figure 17. Submersible or areas at risk of annexation to the sea and other lands at altitudes <1m and at risk for submersion and/or erosion map (APAL/PNUD, 2016)

IV.3. Socio-economic Vulnerability

The physical vulnerability of the Tunisian coastline to sea level rise leads to various direct and indirect socio-economic impacts such as: The loss by flooding of approximately 16,000 hectares of agricultural land in low-lying coastal areas; loss by submersion of approximately 700,000 hectares of built-up areas; Loss by salinization of about 50% of the resources currently available in coastal aquifers; Indirect losses of the potential of the irrigable area of about 38,000 ha, by 2050, i.e. 10% of the current irrigated area; The deterioration of the activity of the seafront hotels, with a total capacity of approximately 30,000 beds, due to the withdrawal of the beaches; Degradation of port and coastal infrastructure;

According to the Intended Nationally Determined Contributions report, the losses in productive capital caused by this damage amount to approximately 2 billion US\$. Annual production losses are estimated at around 0.5% of current Gross domestic product, mainly from tourism (55%) and agriculture (45%) and job losses are estimated at around 36,000 jobs mainly in agriculture, agriculture and tourism; Significant effects may also occur on marine ecosystems, but they are still poorly assessed and require additional studies to better identify and quantify them. Beforehand, continuous monitoring and observations will make it possible to collect the necessary data on this subject. On the basis of the adaptation strategy of the coast to Climate Change, the adaptation measures adopted relate essentially to the rehabilitation and the fight against coastal erosion, the redevelopment and relocation of coastal industrial zones, the rehabilitation and protection of existing infrastructures against the risks of climate impacts and the establishment of aquaculture farms and infrastructures. The total amount was estimated at \$556 million.

V. Assessment of achievements

V.1. Protection actions against marine erosion

The selection of a coastline protection strategy for a specific site is primarily influenced by the protection goal to be attained as well as the erosion-causing factors. Two 80-meter long spikes were implanted in 1990 for the site of the north coast of Sousse, south of the port of El Kantaoui, together with a about 170-meter-long high-strand talus. Between the spikes, a loading in coarse sand (0.2 D50 1.25 mm) was also done. The protected beach extends for about 500 meters south of the port. In terms of a predominance of coastal sedimentary transit, the spices constitute the best works (Milton Hunter, 1992). However, the coastline directly south of the port of El Kantaoui is currently experiencing a problem with noticeable erosion. About 2 kilometers of this region are located south of the port. The port digs being built in front of and to the south of the port of El Kantaoui are directly responsible for the erosion issues. The two spices' construction in 1990 was the sole thing that prevented local erosion. Any steps that are done should lessen the detrimental effects of port excavations and maritime erosion south of the already-existing structures. According to numerical model predictions, without new arrangements for the next ten years, the decline of the spice coast to the south will reach 10 to 20 m (I.H.E, 2000). On the basis of this, it may be concluded that steps must be done to prevent erosion on the beach south of the port of El Kantaoui and to restore it. As part of the National Program for the Protection of the Tunisian coast against marine erosion, which is being directed by APAL, a number of alternatives for the use of mixed solutions to protect the northern shore of Sousse are being examined (APAL,2018).

V.2. Evolution of the situation

The site on the coast of Sousse is one of the priority sites selected within the framework of the national program for the protection of the coast against marine erosion piloted by APAL. This site is currently being studied by the SCET-TUNISIE/NEDECO group of design offices (APAL 2004). And in order to predict the evolution trends of the current situation and the proposal of adequate solutions for the protection of the North total bed of Sousse against marine erosion, the SCET TUNISIA/NEDECO group has resorted to the use of the model numerical (Unibest) for forecasting the evolution of the coastline. In this model, the southern breakwater of El Kantaoui port and the grayness to the south of it were entered as initial conditions. This model simulates the current situation of the beach north of Sousse. It makes it possible to carry out quantitative forecasts on the rate of erosion of the coast south of El Kantaoui port, in the event that no measures are taken to rehabilitate the beach.

VI. Conclusion

Sousse's government is located in the country's center-east it covers an area of 2308 Km² which present 1.7% of the total area of the national territory. The majority of the region's topography is made up of plains, with an elevation of no more than 85 meters. The Sousse area is made up of 16 deputies. The governorate of Sousse has Four tourist hotspots: Sousse-ville, Hammam-Sousse, El-Kantaoui, Chott-Mariem-Hergla, and Yasmin-Hammamet. The coast line of the Sousse Governorate stretches for around 85 kilometers along its length and is dominated by its sandy beaches. The beach measures 100 meters to the north of the governorate and 20 meters to the south. The sandy beaches are located in The Grand Sousse coast is an homogeneous segment of coast The rocky coastline and cliffs are notable in Hergla. The erosion of sandy beaches in Sousse has become a significant impediment to the development of beach tourism in the region. The degradation of the coastal line, particularly along the city's degraded coastal stretch extending from the fishing and trade port to the left bank of the oued Hamdoun, has created multiple challenges for the tourism industry. This portion of coastline accounts for a substantial 39% of the total coastline, intensifying the pressure on the remaining tourist beaches and leading to over-exploitation, particularly of the Boujâafar beach. Urbanization, infrastructure development, and human activities have contributed to sedimentary imbalances, exacerbating the erosion phenomenon. The consequences are far-reaching and include socio-economic vulnerabilities. Moreover, the predicted effects of climate change on the coast, particularly rising sea levels, further compound these challenges.

Efforts have been made to address erosion, including protective measures and numerical modeling to forecast coastline evolution. However, much work remains to develop effective strategies to combat erosion, rehabilitate beaches, and ensure the sustainability of beach tourism in Sousse.

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