Coastal Protection Measures

Tunisian scale

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Co-Evolve4BG

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

Coastal protection measures

Tunisian scale

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OVERVIEW

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REVIEW

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APAL	Agence de Protection et d'Aménagement du Littoral
DPM	Maritime Public Domain
GIZ	German Agency for International Cooperation
IPCC	Intergovernmental Panel on Climate Change
ITCP	Integrated Territorial Climate Plans
MALE	Ministère des Affaires Locales et de l'Environnement
MED	Mediterranean
NGT	National Green Tribunal
NW	North-West
PNA	National Adaptation Plan
PPLT	Program of Protection of the Tunisian Coast
SE	South-East
SNDD	National Sustainable Development Strategies
SLR	Sea Level Rise

Abstract

Climate change is a confirmed phenomenon on a global scale. This manifests itself in phenomena such as the increase in the temperature of the atmosphere and the oceans with the significant evolution of the average sea level. Climate change is also likely to amplify natural pressure factors that perpetually shape the coastal domain by coastal erosion processes and marine submersion of low-lying areas. This could lead to negative and irreversible impacts on the morphological balance of the coastline, the sustainability of marine and coastal ecosystems, the abundance of natural resources and the stability of coastal infrastructures. On the scale of Tunisia, the reality of global warming has become unequivocal. Many negative impacts on the coastal environment and natural resources are already beginning to be felt on the Tunisian coasts with the instability observed at the level of coastal morphological forms, the flooding of low-lying coastal areas, the appearance of several exotic species in the marine environment at the expense of native species. Thus, to achieve the objectives of this mission, the following chapters are present in this deliverable:

- A summary of key commitments and strategies related to the protection of the coastline against erosion and the effects of climate change.
- An overview of the vulnerability of the coastline to the effects of oceanographic hazards in relation to climate change.
- A review of the actions carried out for the protection of the coastline against marine erosion.
- An assessment of the actions carried out for the protection of beaches in tourist areas.

I. Strategies for coastal management

Since the creation of the Ministry of the Environment in the late 1980s, Tunisia has an institutional and regulatory system as well as a set of commitments in favor of sustainable coastal management.

I.1. A regulatory framework in favor of coastal protection

Tunisia is a signatory to almost all international conventions relating to the protection of the environment in general and the coastline. These conventions prescribe measures and guidelines of international scope for the coastline's protection and preservation. Overall, these conventions encourage the integrated management of coastal zones, the creation of protected coastal areas, the fight against pollution and the control of human pressure on the coast.

Many conventions can be recalled: the United Nations Framework Convention on Climate Change, the Paris 2015 Climate Agreement, the Barcelona Convention, the ICZM Protocol, the Convention on the Law of the Sea, Agenda 21 of the Rio Declaration, the Ramsar Convention, the Convention on Biological Diversity, the IMO conventions, *etc.*

Thus, within this framework of fighting against coastal degradation, Tunisia has put in place several measures to try to remedy the losses observed in terms of habitats, beaches, landscapes, historical heritage, *etc.*

In 1992 a coastal charter was the first founding act of Tunisia's interest in the development and conservation of its coastal areas (following the commitments made under the Rio agreements and particularly Chapter 17 of Agenda 21 of the United Nations).

In 1993, an action plan for the development and management of the coastline was drawn up. The objective is to ensure the sustainability of development through the protection of its natural and cultural heritage, the enhancement of its wealth and its integration with the whole territory and regional environment.

In 1994, the notion of coastline was first legislated through the promulgation of the Regional Planning and Urban Development Code (Code de l'Aménagement du Territoire et de l'Urbanisme) which provided the regulations related to the coastline in its article 25.

In 1995, the first legislative acts defining the coastline and the first strong legislative act in terms of coastal protection is found in the two laws 95-72 is 95-73 of July 24, 1995, which respectively created the Agency for Coastal Protection and the management of the DPM. These laws are fully in line with the implementation of the recommendations of the MED.21 conference. Currently, the Ministry of the Environment and Land Use Planning (Ministère de l'Environment et de l'Aménagement du Territoire) is in the process of updating Law 95-73 of the DPM to consider the Sea-Level-Rise (SLR) in relation to the CC. In 1998, the Ministry issued a decree highlighting the sensitive areas that require the development of a Management Plan. This list has focused on sites where land pressure represents a real threat.

After the 2011 revolution the new constitution of January 27, 2014, has given concrete expression to the right to a healthy environment. It is Article 45 of the constitution which provides that "The state guarantees the right to a healthy and balanced environment and contributes to the protection of the environment. It is incumbent on the State to provide the necessary means for the elimination of environmental pollution".

I.2. Strategic commitments to coastal protection

Several studies of a strategic nature have been carried out to ensure the protection and preservation for future generations of all the sensitive natural areas that extend over the 2,290 km of continental, island, and lagoon coastline.

These studies began in the early 1990s with the General Direction of Air and Maritime Services (Direction Générale des Services Aériensand Maritimes-DGSAM) of the Ministry of Equipment on the Technical Aspects. It was on the year 2000, after the creation of APAL, that these studies focused on the issue related to Sea Level Rise (SLR) induced by CC.

DGSAM, 1995: «General study for the protection of the Tunisian coastline». This is the first global study on the entire Tunisian coastline which has gathered all the information on coastal dynamics. It consisted of the following 5 parts:

- Report 1: Inventory of Existing Structures.
- Report 2: Updating of meteorological data and wave simulation.
- Report 3: Statistical estimation of swell.
- Report 4: Updating hydraulic data.
- Report 5: Update of sedimentological data.

Ministry of the Environment and Sustainable Development (Ministère de l'Environnement et du Développement Durable) 1998 and update 2009: «National Biodiversity Strategy and Action Plan». The 2009 strategy is based on 6 axes which cover the different aspects of biological diversity in Tunisia, namely:

- Conservation of biological diversity in Tunisia.
- Integration of Biodiversity Conservation and Natural Resource Management.
- Management of processes threatening biological diversity.
- Improvement of biological diversity management tools.
- Mobilization of partners.
- Institutional reinforcement for the implementation of the Plan.

Ministry of the Environment and Sustainable Development, 2008: «Study in link with the environmental and socio-economic vulnerability of the Tunisian coastline to sea level rise and identification of an adaptation strategy based on the third IPCCreport of 2001».

The main axes retained in this strategy are the following:

- Reinforcement of the knowledge on the parameters related to the SLR.
- Strengthening the physical capacity to adapt.
- Strengthening the stability of ecosystems with changes in diversity.
- The sustainability of fish stocks and exploitable species.

APAL (Agence de Protection et d'Aménagement du Littoral), 2012: «National Adaptation Strategy of the Tunisian coast to the effects of climate change». The main strategic axes retained in relation to the CCs concern:

- The development and optimization of fishing and aquaculture through a better organization of fishing campaigns, a thoughtful evolution of the fleet and a better exploitation of the potentialities of aquaculture.
- Development and repositioning of coastal biodiversity adaptation policies.
- Integration of the impacts of climate change into the National Spatial Planning Scheme.
- Development of Integrated Territorial Climate Plans (ITCPs) in priority coastal areas, the Djerba Island, and the Governorate of Bizerte.
- Strengthening and adaptation of legal mechanisms.
- Strengthening and adapting the legal, institutional and governance; and mechanisms for shoreline management by integrating the climate change adaptation component.

APAL, 2012: « Mapping the vulnerability of the Tunisian coastline to sea level rise » This mission allowed to:

- Identify the different types of morphologies characterizing the coastline.
- Mapping the different types of coastal wetlands.
- Mapping areas vulnerable to sea level rise.
- Publish an atlas on the vulnerability of the coastline to sea level rise.

Ministry of Tourism (Ministère du Tourisme), GIZ, 2010: « Tourism and climate change in Tunisia: National strategy for adaptation to climate change in the tourism sector in Tunisia ». The adaptation strategy is articulated around four major axes:

- Improve building management.
- Consider the degradation of tourism resources while developing the tourism sector.
- Improving the country's tourism offers to limit the vulnerability of the activity.
- Rethinking more energy-efficient transport modes.

These axes are translated into 15 strategic orientations, the aim of which is to:

- Reduce the vulnerability of Tunisian tourism by limiting its dependence on resources likely to be degraded (primarily beaches and fresh water) while valorizing less vulnerable resources.
- Better exploit the climate potential by improving heat management and changing the spatial and seasonal distribution of tourism.
- Reduce the vulnerability of Tunisian tourism to the international economic situation in link with the price of energy and the "carbon constraint" by reducing its dependence on fossil fuels and its CO_2 emissions.

Ministry of Local Affairs and Environment (Ministère des Affaires Locales et de l'Environnement) MALE, 2015:«Planned Contribution at the National level of Tunisia under the United Nations Framework Convention on Climate Change».

Tunisian Government (GouvernementTunisien), Five-Year Development Plan 2016-2020: In its development plan 2016-2020, the Tunisian government has adopted of the green economy as a driving force for sustainable development. This axis includes several aspects, namely:

- Balanced land-use planning that integrates all regions and respects the environment.
- The control and rationalization of the use of natural resources: the control of the use of water resources, the protection of natural wealth and a modern agriculture that guarantees food security.
- The protection of the environment and the natural environment.
- Controlling energy consumption.

MALE, 2015: «National Sustainable Development Strategy». The national sustainable development strategy (SNDD) finalized in 2014 was based on the concept of concertation, of the exchange and common identification of strategic axes and objectives to be achieved at least up to the level of the predefined time horizon of 2020. On that base, the SNDD has selected 9 challenges of sustainability that Tunisia will have to overcome in the future represented in 42 strategic axes. The 9 objectives are the following:

- Establish sustainable consumption and production integrating the concept of green economy.
- Promote a high-performance economy, strengthen social equity and fight against regional disparities.
- Sustainable management of natural resources.
- Promote a more balanced land use planning based on efficient and sustainable transport.
- Promote a better quality of life for citizens.
- Develop energy efficiency and promote renewable energies.

- Strengthen the capacity to adapt to climate change.
- Promote the knowledge society.
- Adapting governance to better promote sustainable development.

Ministry of Agriculture, Hydraulic Resources and Fisheries (Ministère de l'Agriculture, des RessourcesHydrauliques et de la Pêche), 2019-2020: « National Adaptation Plan », the PNA, in its final phase of publication, intends to analyze, evaluate, and propose, for key economic sectors, adaptation options to deal with the expected effects (by 2050 and 2100) of climate change.

II. Vulnerability of the beaches due to the SLR

II.1. Factors Affecting Beach Vulnerability

Coastal zones are dynamic systems that operate continuously. Sea level is one of the main parameters determining the position of the coastline. Relative SLR generally results in a retreat of the coastline unless this trend is compensated for by rapid re-deposition. Also, a rise in sea level will influence sedimentation process. The later will be faster with a different distribution of sediments from the current state to another equilibrium state.

Sediment inputs and pre-existing morphology are crucial factors in controlling coastal changes due to sea level rise. Indeed, SLR could trigger a sequence of events that leads to another state of equilibrium, both at static and dynamic scale. There are several reasons why sea level could lead to beach erosion or accelerate the retreat of the coastline:

- The variation in the intensity and direction of the energy flow of the swells (height, period, speed, direction, etc.).
- The dissipation of wave energy on the most vulnerable beaches.
- Deeper water decreases wave refraction and thus increases the shoreline transport capacity.
- With a high-water level, wave and current erosion processes will act higher on the beach profile, leading to a readjustment of the sand migration profile.

Depending on the type of beach, the wave reaction as well as the type of sedimentation will be different as well:

- The swell that reaches the reflective beaches breaks on the coast. A rise in sea level will have less of an impact than on dissipative beaches.
- Dissipative sandy beaches are the most vulnerable to SLR. Indeed, the swell is much more energetic and will move closer to the beach to break and carry the sand out to sea. In this case the withdrawal will be more important.
- Sand beach normally is made of fine to very fine sand which will tend to migrate.
- Fine beach sands tend to migrate towards the open sea. A coastline made up of fine sand will respond positively to the SLR.
- A coarse sand coastline will respond slowly to sea level rise. Coarse-grained coastlines will be the least vulnerable to SLR.
- A coarse-grained coastline is less affected by SLR.
- A long beach will respond slower to SLR.
- Climate change is causing flooding that will lead to supplying the low areas (sabkhas and lagoons) and on the coast via rivers and wadis with sand which will cause a change of the nature and granulometry of the sediments.

II.2. Vulnerability of Tunisian beaches to the SLR

The transformations of the coastal system, that are likely to occur because of CC, include a modification of the coastal sediment budget regime, a changing of the current sedimentation process and an acceleration of coastal erosion.

Based on the morphological characteristics of the beaches presented in deliverable 1 and on local oceanographic characteristics, the vulnerability of beaches to SLR for each of the coastal regions studied is presented in the following paragraphs.

II.2.1. The extreme North

The north coast, which is characterized by a succession of rocky coast and pocket beaches with medium-sized sediments down to a depth of -5 m, is formed by small beaches of intermediate. They are characterized by a pronounced slope and a breakwater that generally occurs between 50 and 70 m from the beach. These beaches are essentially characterized by a reduction in longitudinal transport compared to transverse transport. The rise of the sea level results in a break-up much closer to the coast with a higher energy. Part of the sand present on the coast will tend to migrate offshore with a probable dissipation of the scalloped bars. However, the presence of a significant embankment with medium to coarse sands will have the advantage of delaying erosion and loss of sedimentary material. Also, the variation of the sediment balance of these beaches or of the agitation conditions leads to an adaptation to the new conditions with a redistribution of the sediments along the shoreline, until it finds a new static balance. This adaptation is mostly demonstrated by the rotation of the coastline in response to a change in wave incidence. The coastline will thus form traps where sand cannot escape laterally and are thus quasi-independent sediment cells.

In addition, in long-term, these beaches generally tend towards a cross-shore transport linked to the sea rise proposed by Bruun (Bruun, 1962; see Deliverable 01). However, the coarse grading of the beach sands may reduce the seaward movement of sand, in which case the north coast will be less vulnerable to the SLR.

II.2.2. Gulf of Tunis

The beaches of the Gulf of Tunis are longer than the beaches of the north coast and are rather dissipative type sometimes intermediate. Generally, the sand on the coast is fine from Bizerte to Hammam Lif which becomes medium in Soliman, Port aux Princes and Sidi Daoud. The SLR will lead to a migration of the underwater bars that supply the beaches through the longitudinal coastal transit to the open sea. Probably other bars will take over but at the expense of the beach sand. This migration is particularly concerned with areas of fine sand (coast from Bizerte to Hammam Lif). On the other hand, the coast extending from Soliman to Sidi Daoud will be less affected by the SLR.

It should be noted that several parameters must be taken into consideration while evaluating the impact of the SLR on the coastline evolution. Among these parameters is the supply of sand to the coast via rivers. The main rivers that feed the Tunisian coast flow into the Gulf of Tunis. The supply of sand by these rivers can induce the changes of the sedimentation and impacts of the SLR.

II.2.3. Gulf of Hammamet

The particularity of this northern section is the extent of these sandy beaches. The sand on the coast is essentially medium in the north passing to course between Hammamet and Hergla. The petrography of the sedimentation zone as well as the significant length of the beaches is in favor of reducing the negative impacts of SLR. On the other hand, the beaches in this sector are of a dissipative or even intermediate type, which allows us to classify this sector as being little too vulnerable to SLR.

II.2.4. Central Sahel

Morphologically and sedimentologically, the section of coast from Hergla to Chebba is very heterogeneous. The area from Hergla to the cliff of Monastir is composed on the coast of medium to coarse-grained sedimentary rocks. The beaches are of reflective to intermediate from Hergla to El Kantaoui becoming later dissipative between Sousse and Monastir. Based on the parameters of vulnerability to SLR reported earlier, it can be argued that the northern part will be less influenced by SLR than the southern part, which includes the coastal line from Khezama to the Monastir cliff.

The sedimentation in the bay of Monastir is of muddy to very fine sand type with a very low slope and a very limited swell and located more than 1km from the coast. In this context, this area will be more prone to submersion than to erosion due to a change in marine dynamics.

Further south between Bekalta and Chebba, the dynamics resumes with a breakout distant from the coastline between 50 and 100 m. The beaches in this sector are essentially energy dissipative. The sand is fine to medium. In this case, this sector can be classified among the vulnerable sites to the SLR.

II.2.5. Gulf of Gabès

The Gulf of Gabès is considered as a platform with a very low slope. It is constituted by very fine sediments or even muddy. The breakwater is very small. The only area where the break-up occurs near the coast is the spit of Chaffar and the coast of the city of Gabès. The submergence will be more important on the muddy coasts than the erosion phenomenon. On the sandy coasts, following the rise of the sea level, the marine dynamics change and the break-up occurring on the sandy bars will progress intensely towards the coast. The fine sand that settles on the bottom will migrate towards the open sea leading to a change in the morphology of the coast.

II.2.6. The extreme South

The coast between Boughrara and Ras Jedir is characterized by a rocky coast in the south and sandy in Zarziss. The seabed is mainly rocky. These observations have shown that this section will respond very slowly to the effects of the SLR, and the rocky bottom will tend to attenuate the energy of the waves.

II.2.7. Djerba Island

The coasts of the Djerba Island are different. The hydrodynamics is more energetic on the NW and SE coasts, with a break on straight bars distant from the shoreline from 30 to 200 m. The sediment is characterized by fine grain size. A rise in sea level will result in a considerable loss of sand. Indeed, the underwater bars, which are the source of power for the beaches, may migrate to greater depths. Feeding the coast with terrestrial contributions (cliff erosion and contribution by rivers) will tend to balance the loss of sediment and will lead to the installation of coarser sedimentation.

III. Actions carried out to protect beaches from erosion

III.1. General overview of protection methods

For the protection of coasts against marine erosion, two types of protection techniques are used, namely:

- The so-called hard techniques have the characteristic of freezing the coastline.
- The so-called soft techniques have a more environmental approach.

III.1.1. Hard techniques

The hard techniques are affiliated to those involving the construction or installation of solid structures whose action is to maintain the coastline or modify the evolution of its geometric configuration. These protection techniques are of four types, namely:

Longitudinal constructions: This category of (longitudinal) structures is arranged along the coastline either directly at the land-sea interfaces at the waterfront or at the foreshore.

Waterfront constructions: They are most often made up of masonry stones (riders) and riprap made of concrete or another material used to protect the slope of an embankment. They are designed to withstand wave action and storm assault and allow for little erosion.

Fore-coast constructions: They are made up of structures located in front of the coast. They are partially or totally submerged structures that retain sediments. The principle of operation consists in creating a wave breaking and a loss of energy by absorption and reflection. They are arranged approximately parallel to the coast. Their function is to reduce the action of the wave and encourage the deposition of sediment at the back of the structure.

Transversal constructions: This category includes structures that maintain sediments and allow the accumulation of sand such as groins. These are relatively short riprap structures that advance into the sea from the beach and whose main function is to interrupt the coastal transit of sediment in order to create or retain beaches at a higher level (and often, in so doing, to protect an existing sea defense structure).These groins can have different shapes, they can be straight (perpendicular to the coast) or Y-shaped, L-shaped or T-shaped. They can cumulate at the same time the function of the groin and of the blade breaker and they can be associated with sand refill.

III.1.2. Soft techniques

These soft techniques have developed since the 1980's and have designed to work with nature by integrating the natural dynamics of the coastline and coastline mobility. As with previous techniques, soft protection can be longitudinal or transverse.

Longitudinal protection can be carried out either at the waterfront by stabilization with forks, buried geotextile, or by hard facing, or at the foreshore by geo-tubes filled with sand.

Transverse protection can be carried out at the bottom of the beach by permeable hydraulic piles or by geo-tubes filled with sand.

Longitudinal stabilization by forks: Dunes can be stabilized through a flexible management to ensure a degree of mobility. The basic principle is the moderation of wind erosion by reducing the wind speed through the installation of windbreaks, formed by forks. Their effect is to provoke a sudden drop in wind speed after it has passed through them, hence the deposition of some of the sand that it carries (Fig. 1).

Figure 1. Forks placed on the beach of Mahdia

Longitudinal stabilization by geotextile: This technique consists of creating flexible obstacles formed by geo-tubes filled with sand that can be placed either directly on the coast to retain beach sand or at the fore-beach to reduce the effect of the wave on the beach.

Recharging beaches: Beach or foreshore recharge, is a widely used technique. They are intended to compensate for the imbalance resulting from natural erosion or human action (rigid protection structures to fix the coastline, construction of port structures that block coastal transit or river structures that limit sediment input). These operations involve offshore sand extraction and impacts on ecosystems. In addition, they generally do not provide a permanent solution to sediment loss. It is therefore necessary to know the zones to be recharged and the balance profile of each beach to allow optimal recharging.

Stabilization of the lower part of the beach by hydraulic piles: Stabilization of the beach bottom can be carried out by hydraulic piles, which are wooden posts planted vertically in the sediment at regular intervals. They can be implanted parallel or perpendicular to the shoreline on the foreshore often over several tens of meters. These permeable structures are used to dissipate wave energy on the beach, thus limiting sediment transport and promoting beach stability (Fig. 2).

Figure 2. Stabilization of the lower beach by hydraulic piles

III.2. Hard coastal protection measures in Tunisia

The action of protecting the coasts against marine erosion began in the late 1970s with the traditional methods of hard protection structure. In the early 1980s, violent storms have caused extensive damage to the coast of the city of Tunis, and it is from this date that hard structures have multiplied to protect the Tunisian coast. The structures implemented are composed of rockfill jumper, groins, and breakwaters. Following, we present the hard coastal protection measures located at Tunisian coastline (from the north to the south).

III.2.1. The extreme North

The Cornice of Bizerte: The protection structure was built in 1992 and is located at the end of a sandy beach. The protection extends over a 650 ml linear made up of two parts:

- A part consisting of a protective embankment made of riprap on a 266 ml line with riprap of 0.5 to 2 T leveled at a slope varying from +3.5 to 4.5 m NGT.
- A second part consists of a solid soil retaining wall behind and composed of a 385 m long reinforced concrete shells. This is a retaining wall protecting the cornice of Bizerte is L-shaped and protected at the foot by riprap of 0.1 to 0.5 T.

Caves of Bizerte: A 200 ml rockfill jumper was made for protection against marine erosion.

The site of Menzel Abdurrahman: It is a structure for Menzel Abdurrahman's shore protection. This structure is exposed on the lake of Bizerte. It is also composed from a reinforcing wall built in 1992 on a linear of the order of 100 ml and identical to that of the cornice of Bizerte. It is built to protect the town of Menzel Abdurrahman against the agitations induced in the lake of Bizerte.

The site of Rafraf: Exposed to very severe erosion problems, this site has been subject to two stages of protection:

1st step in the 1990s: A coastal street is protected from the action of the sea by a protective structure that was built in 1992 based on a sandy beach. It extends over a 300 ml linear. This structure is made up of an embankment dike protected by a 1 to 2 T riprap carapace and leveled at the coast +3 m and having a depth of 1 m.

2nd step during 2016– PPLT: A 2000 m section of the coast was protected by the realization of hard and soft methods including (APAL, 2019):

- A spike plunging 395 m long.
- Beach recharge with a total quantity of sand of about 500,000 m3 on a 2,000 m line (Fig. 3).

Figure 3. Rafraf Beach Protection Works, 2018

III.2.2. The Gulf of Tunis

The Site of Sidi Ali El Mekki: To prevent the coastal erosion, two rockfill groins 260 and 190 m long have been installed at 400 and 800 m respectively and parallel to the main eastern dike of the Port of Ghar El Melh, which has been extended over a 150 m line. The two groins are riprap embankments with a shell of 0.5 to 3 T and 2 to 4 T leveled at the coast from 1.2 to +1.8 m NGT. The extension of the main dike of the Port is ensured by a 4 m^3acropods carapace (Fig. 4).

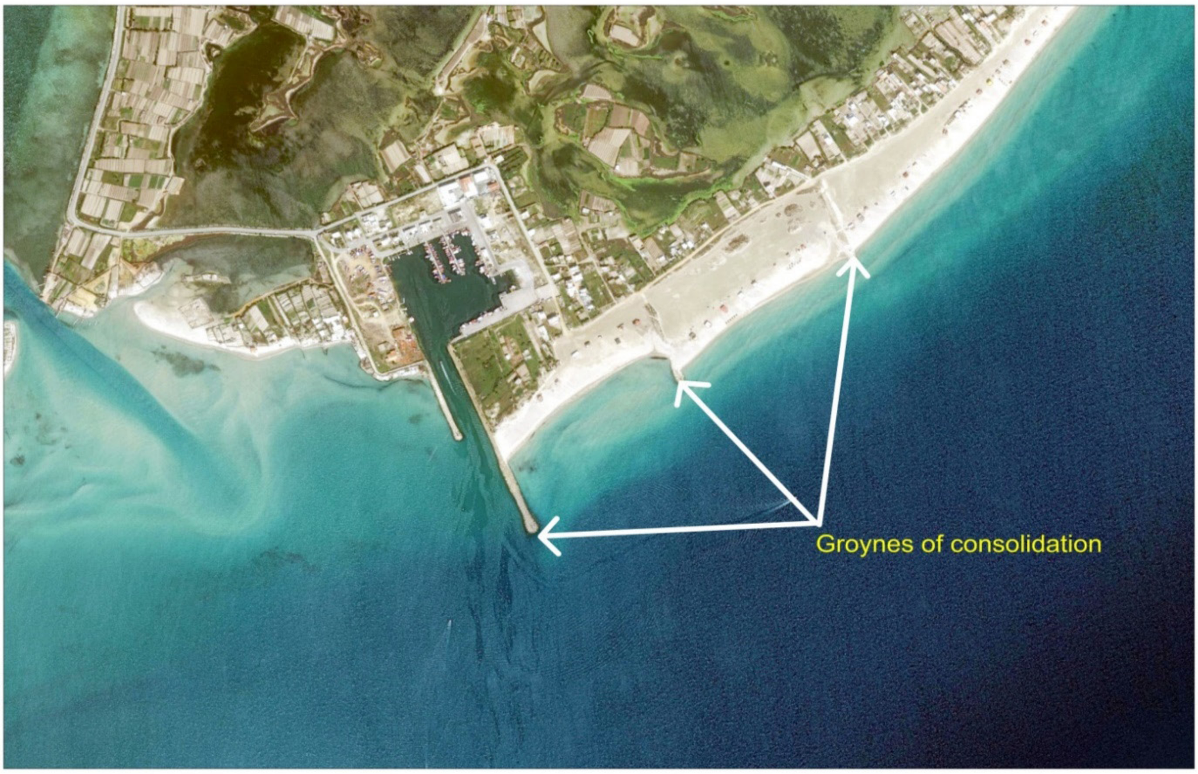

Figure 4. Spikes of protection of the Sidi Ali El Mekki beach

Northern suburb of Tunis: An important set of structures has been installed along the northern beaches of Tunis from Salammbô to La Goulette. These protective structures are designed in carapace of riprap having calibers from 1.5 to 3 T and 3 to 5 T and leveled at a coast which varies between + 1.70 m to 2.00 m (Fig. 5). The coastal protections extend over a total length of 3870m distributed as follows:

Spikes, spread over a length of 1400 m between Salammbô and Kheireddine formed by 2 T riprap.

- A 120 m breakwater.
- A jetty of 200 m in Salammbô.
- Longitudinal coastal protections formed by rockfill embankments with a total length of about 2150 m.

Figure 5. Protection structures for the northern suburbs of Tunis

Southern suburb of Tunis: An important set of protection structures was carried out in the southern suburbs of Tunis in the 1980s. The main purpose of the implementation of these structures is to fight against erosion and to enhance the function of the beaches while recharging them with appropriate sand (Fig. 6). They include 2200 breakwaters and 1700 m of longitudinal protection distributed as follows:

- Rades: A 123 m breakwater, a 200 m longitudinal rock protection.
- Ezzahra: Two 270 m isolated breakwaters emerging from 270 m and 100 m longitudinal riprap protection.
- Hammam Lif: A set of eight insulated breezes emerging from 1000 m, an isolated blade breaker of 100 m and a longitudinal riprap protection of 520 m.
- Solymar: Two isolated breaker blades of 260 m.
- Soliman beach: A set of five isolated breakwater blades of 590 m in length.

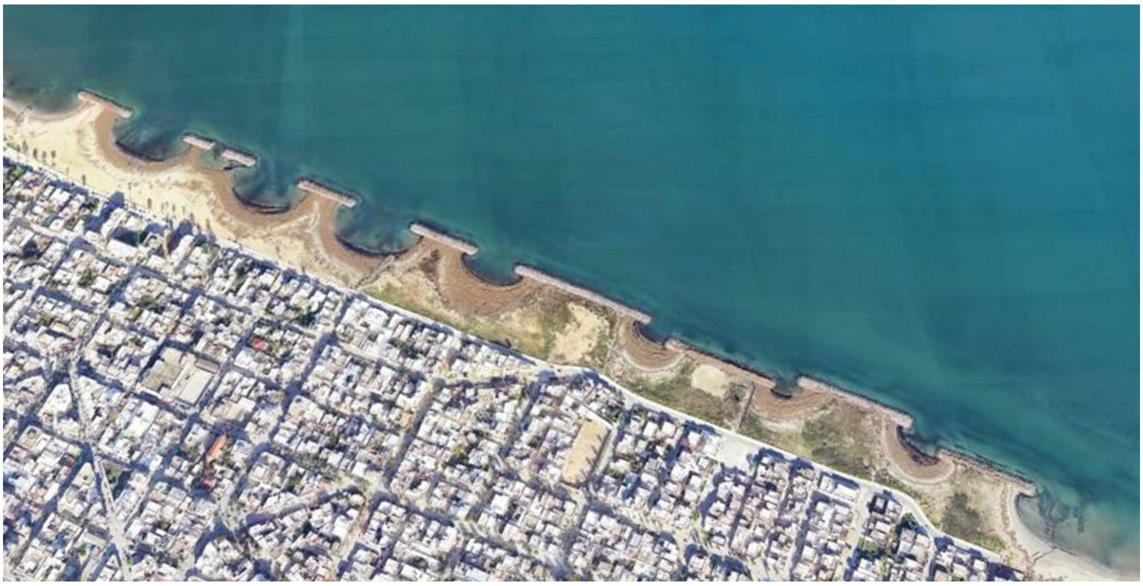

Figure 6. Set of 8 protective breakwaters of Hammam Lif (southern suburb of Tunis)

Most of these structures have consolidated the coastline where they are located, but new problems have appeared, such as disfiguration of the landscape, accumulation of algae, eutrophication of the waters in closed creeks, unequal redistribution of sediments, aggressive erosion in adjacent areas, *etc.*

Soliman Coastal Protection Project against Marine Erosion– PPLT (APAL, 2019**):** The works concern the protection of the coast from Soliman to BorjEssadria against marine erosion (Fig. 7). This work includes both hard and soft protection methods:

- A 350 m long rock rider at the beach of Sidi Jehmi.
- A rock rider at the beach of Soliman with a length of 850 m.
- 5 plunging spikes with lengths between 350 and 370 m.
- Artificial recharging of the beach with an amount of 520,000 m3.
- Removal of five breakwaters at Soliman.
- Cranks on 7 km of beach.

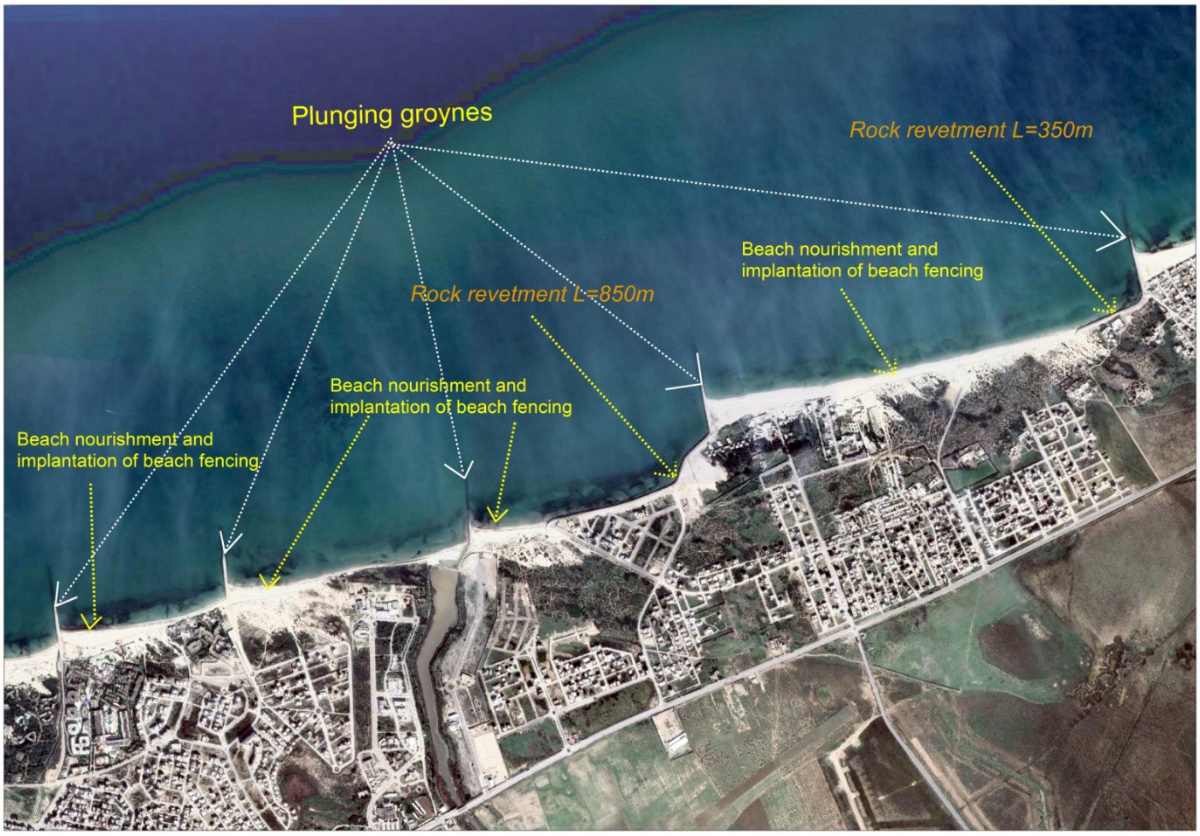

Figure 7. Protection works of the Soliman-PPLT beach, 2016

III.2.3. The Gulf of Hammamet

The site of Kélibia (2017): The section, subject to protection, extends over a total length of 790 m between the beginning of the Sebkha of Kélibia and the end of the hotel El Mamounia (Fig. 8). The work includes (DGSAM, 2015):

- The total recovery of the existing rider on a linear of 705 m.
- The realization of a 15 m long spike.
- The development of the pedestrian platform.
- Reinforcement and artificial recharging of the existing beach.

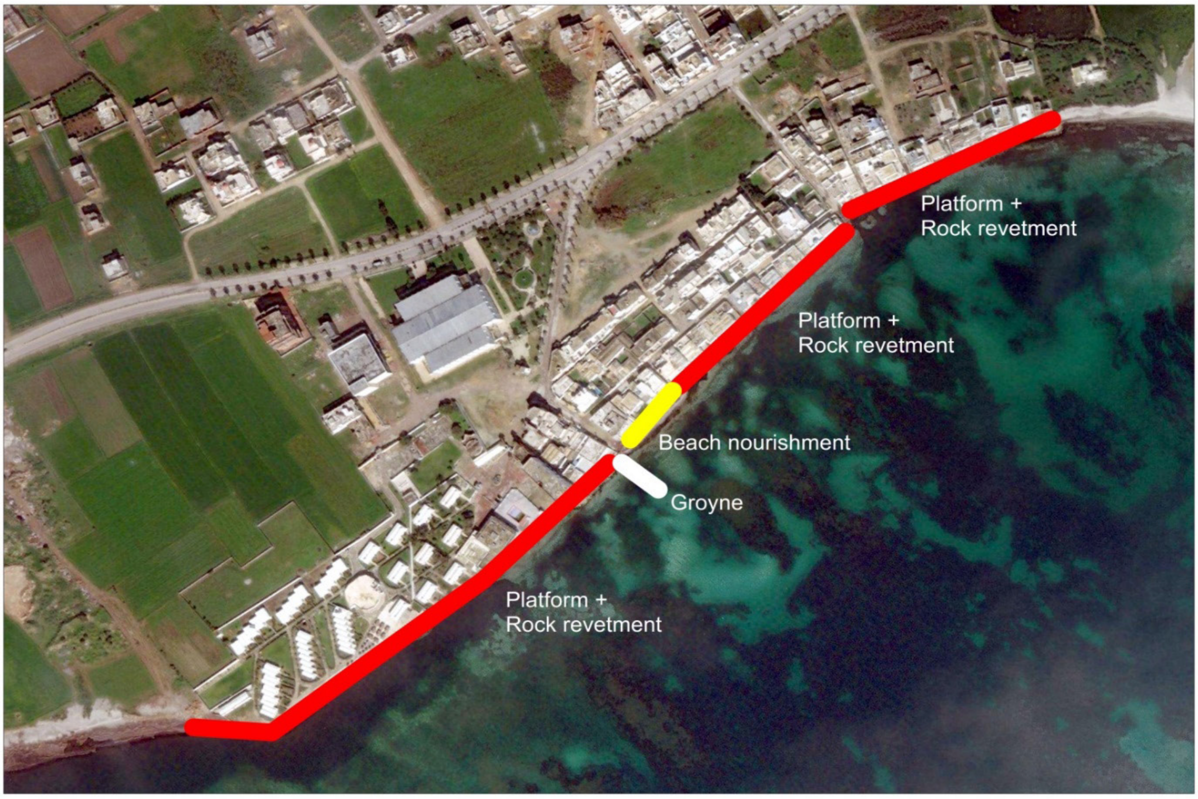

Figure 8. Protection works on the El Mamounia section in Kélibia, 2017

The cornice of BENI KHIAR: After the construction in 1980 of the Beni Khiar Fishing Port located in the North, the marine erosion became quite remarkable. To cope with this erosion, rockfill embankment protection works were carried out in 1990 on the north-eastern part of the site. In 1997, an extension of the Port dikes was carried out. After 2002, to the west of the fishing port of BENI KHIAR, over a length of about 150 m, the protection of the cornice was ensured by two types of rockfill structures, namely:

- An old rock embankment on a 200 m long line.
- A new rockfill structure connecting to the old one is about 100 m long, but with a lower gradient than the old one.
- A set of 4 breakwaters of 80 m each was built in 2008 in front of the Hotel Lido Nabeul to protect its 600 m seafront (Fig. 9).

Figure 9. Set of 4 protective breakwaters of the Lido Hotel

Dar Chaabane: Protection of the coast by an 800 m rockfill jumper. In 2014 and within the framework of the - PPLT project (APAL, 2019), APAL has just enhanced the protection of the stretch of coast between El Madfoun and the fishing port of Hergla over a length of 2000 m with the following actions:

- The realization of four rows of forks on a 400 ml beach line at Hergla El Madfoun and two rows of forks on a 130 ml beach line at South of Hergla.
- The repair of the existing jumper of El Madfoun by the addition of a carapace on a total line of 430 ml.
- The realization of an immersed breakwater blade in front of the beach of El Madfoun with a length of 150 ml.
- The realization of a jumper at the foot of the cliff of El Montazah with a length of 620 ml (Fig. 10).

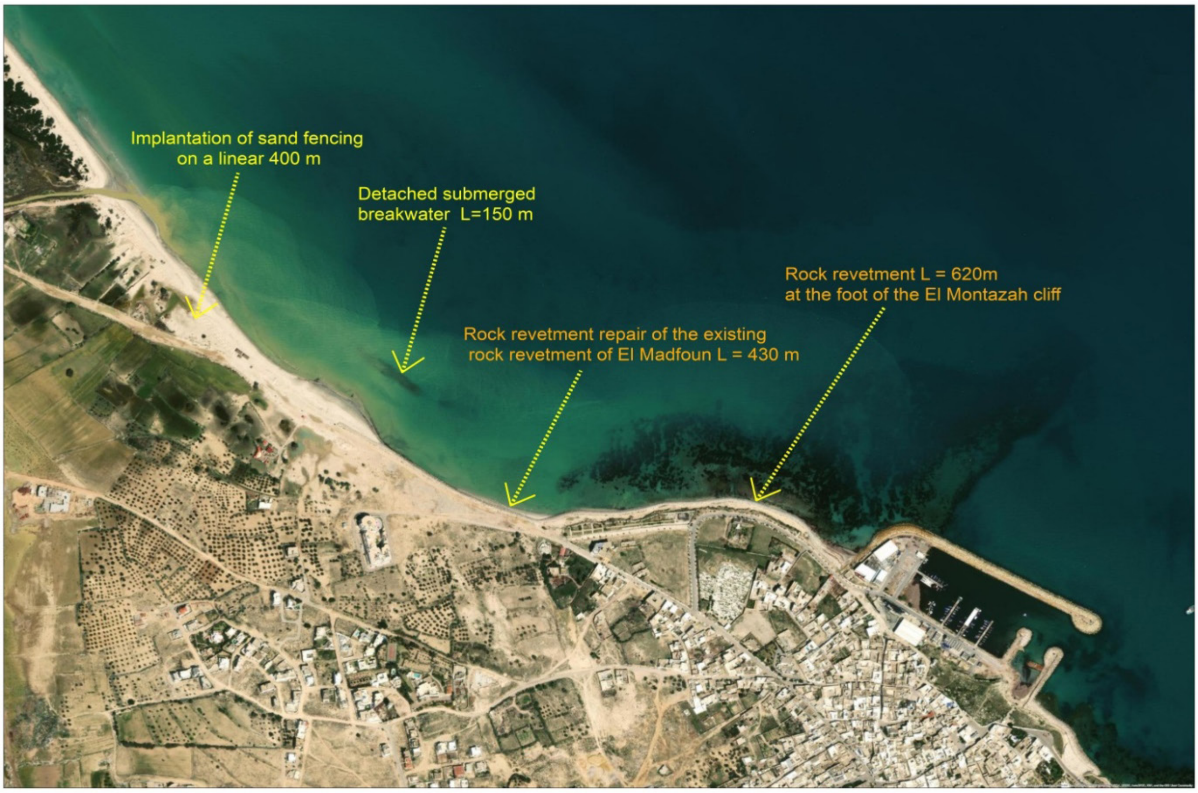

Figure 10. Protection works on the Hergla section, 2016

III.2.4. The Central Sahel

Site of Sousse North: Being one of the most important tourist poles, this site has been the subject of various protection projects against marine erosion including:

1st step to the 1990's El Kantaoui site: The northern beaches of El Kantaoui have undergone in recent years significant erosion phenomena, which is why it was carried out the installation, on a section of 500 m, two protective groins of 80 m long accompanied by a slope of high beach of 170 m long associated with a recharging of coarse sand. These structures are formed by 3 distinct profiles in the form of rockfill dikes composed of a flexible structure of 1 to 500 Kg and 0.5 to 3.6 T. They are leveled at a coastline varying from - 1.00 m to + 1.00 m.

2nd step to the years 2010–PPLT project (APAL, 2019**)**: the protection work includes:

- The realization of three immersed breakwaters of 200 ml each in Chatt Mariem (Fig. 11).
- The realization of four immersed breakwaters of 250 ml each in Hammam Sousse (Fig. 12).
- The realization of a jumper of 100 ml in Sousse port-Hadramaout (Fig. 13).
- The realization of a spike of 20 ml in Sousse Port-Hadramaout (Fig. 13).

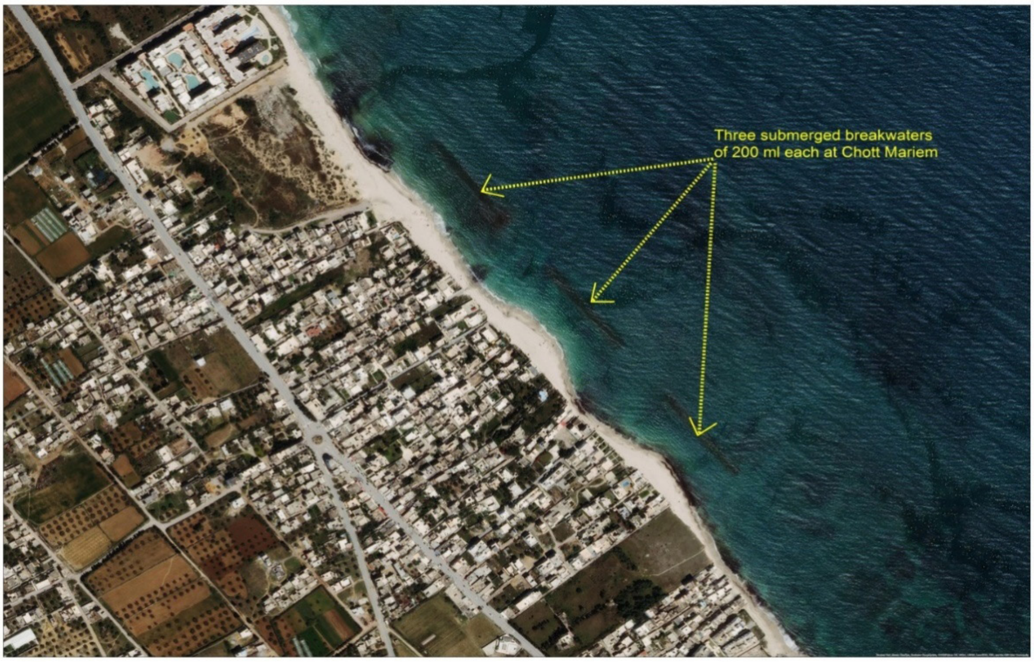

Figure 11. Protection works of the Chatt Mariem section, 2016

Figure 12. Protection works of the Hammam Sousse section, 2016

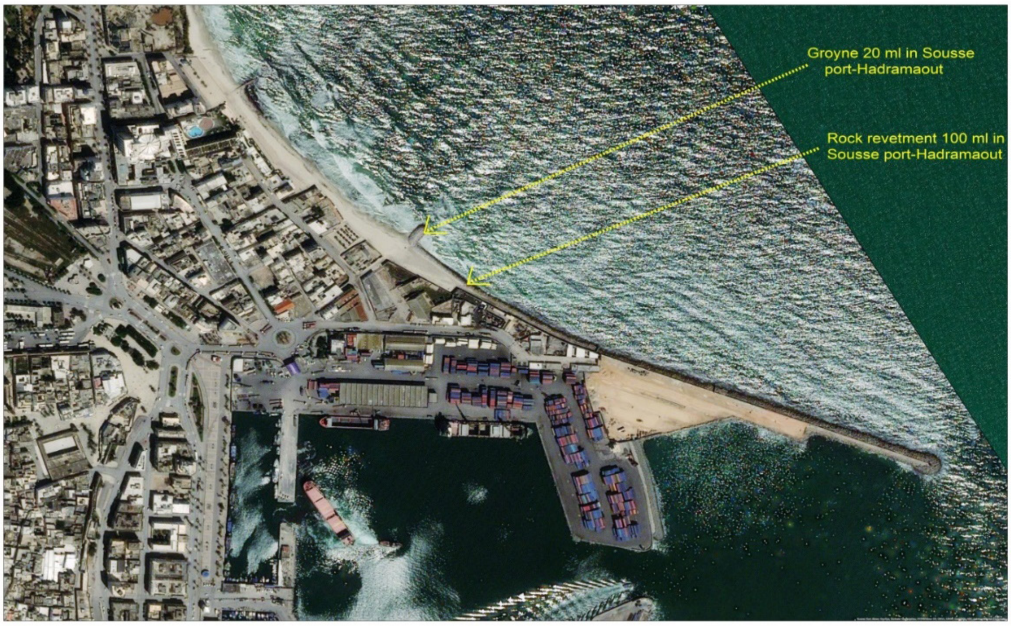

Figure 13. Protection works of the Sousse port, 2016

Site of Sousse South (Sidi Abdelhamid): The southern beaches of Sousse are protected against the effect of the advancing sea by two isolated breakwaters in the sea of 90 m long and a coastal protection on both sides in rockfill embankments. Another protective structure of this beach was established in the south of this area; it is:

- A 150 m long isolated breakwater at sea and.
- A coastal dike built in Tuff and on a length of 300 m approximately.

Site of Monastir: The coast of Monastir has been reinforced in several places following an accentuated vulnerability to the action of the sea on the coast (Fig. 14).

Monastir Skanes: The area of Monastir Skanes is exposed to very severe frontal waves which led the state to realize in the 1980s protections including (Fig. 14):

- Three isolated breakwaters at sea have been set up to slow down the advancement of the sea towards the coast. They are respectively from east to west with lengths of 160 m, 160 m, and 300 m.
- Six protective groins of 75 m long were undertaken perpendicular to the coast.
- Longitudinal protections reinforced by rock embankments.

Cliff of Monastir: Collapses were observed at the level of the cliff of Monastir and led the state to carry out its protection according to three sections (Fig. 14):

- First tranche carried out in the 1990s next to the marina by a rockfill jumper on a linear of 1000 m.

- Second tranche realized in 2012, including:
    - The construction of retaining wall platforms over 300 m of backshore and protected on the seaward side by a submerged breakwater 200 m from the front shore.
    - A rockfill jumper over a linear distance of 700 m.
    - Two Y-shaped groins of 90 m each.
- Third tranche is in progress. It is being made to protect the eroded section. The infrastructure is a 200 m of retaining wall platforms and 300 m of riprap walkway.

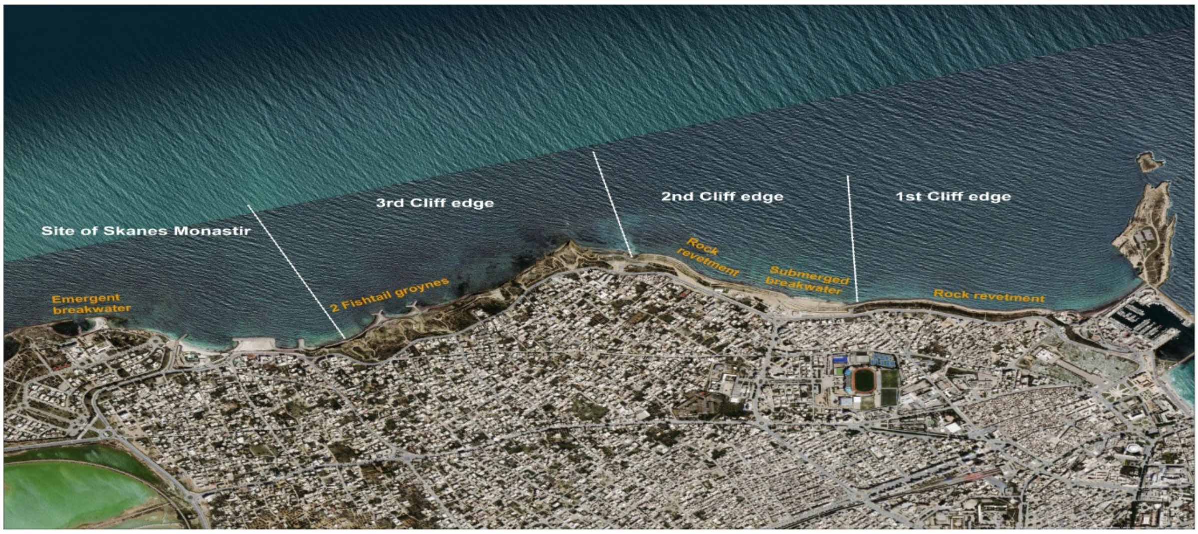

Figure 14. Protections realized on the coasts of the city of Monastir

Site of Mahdia: To face the phenomena of erosion of the coast of Mahdia and the beaches located at the north and south of the fishing port and revalorization of the beaches for the bathing, various protection structures were realized including (Fig. 15):

- North Beaches:The northern beaches of the city of Mahdia are protected by 6 isolated breakwaters at sea, with a total length of 820 m, arranged at 75 m from the shore and having an average length of 140 m for each breakwater. Four of which were built in 1984 to a depth of 1 m and two others in 1993 to a depth of 2 m. The profile of the North breakwater of the slope type is protected by a shell made of 2 to 4 T rock and leveled at the coast +2.50 m.
- Cape of Africa:Following a collapse observed at the Fatimid archaeological site, a submerged breakwater of 200 m was carried out in front of the site.
- Cliff of Mahdia: A rockfill jumper over a length of 130 m was built to protect the cliff starting north of the Sidi Salem café to the archaeological vestiges near the marine cemetery.

- Mahdia south (DGSAM, 2014): the realization of the works of repair and reinforcement of the existing jumper of the section of coast of Mahdia south located just north of the fishing port of the city center on a linear of 300 m.
- South Beaches: The southern beaches bordering the fishing port are protected by a single 110 m long breakwater. However, the corresponding profile is also of the embankment type protected by a rock carapace of 0.5 to 2 T and leveled at the coast +2.50 m.

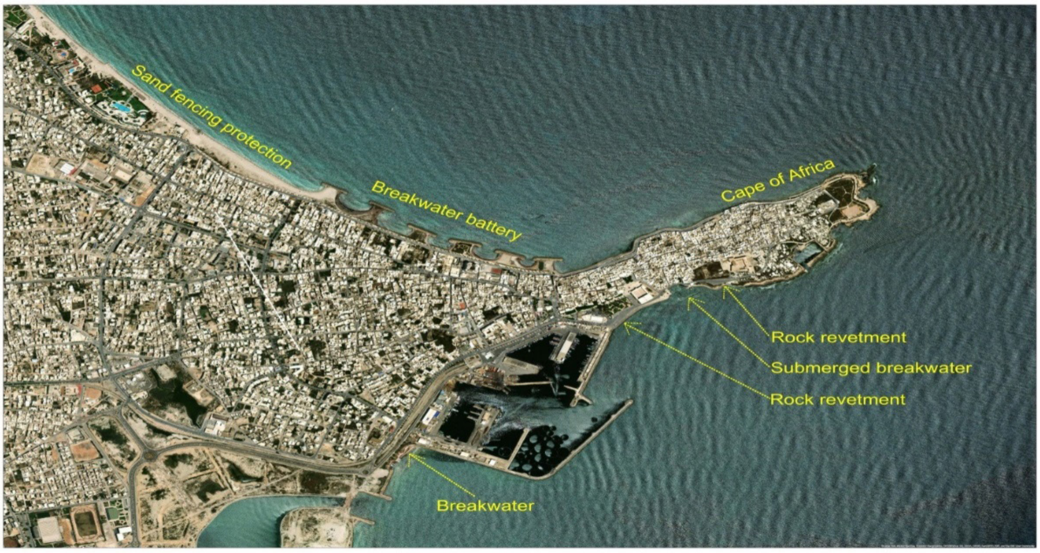

Figure 15. Protections realized in Mahdia

The Site of Salakta: South of the fishing port of Salakta, the protection of the coastal road is provided by a retaining wall of 300 m long and having a variable height of 2 to 3 m and protected at the base by rockfill of 0.3 to 1.5 T. Other protective structures have been planned, particularly to the south of the existing structure, namely a 200 m long shoreline protection and a protective wall to the north of the fishing port, which is 880 m long. The prevention of the implementation of other various longitudinal protections of the coast to the north and south of the Port of Salakta was noted, namely: a longitudinal protection of 200 m south of the existing structure and a protective wall of 880 m long.

Second protection of the Salakta site: An 800 m rockfill protection jumper.

The Site of La Chebba: The east, west and central shores are protected by a rockfill embankment with lengths of 260 m, 320 m, and 200 m respectively. On the East side, a retaining wall was built to protect the coastal road. This embankment has a variable height of 2 to 3 m and is protected by rockfill of 0.3 to 1.5 T.

The Gulf of Gabès and the extreme south:

The Jebeniana site: Two rockfill jumpers were built in the area:

- A rockfill jumper of 500 m at Ellouza.
- A rockfill jumper of 500 m at Hzag.

Islands of Kerkennah: The Kerkennah Islands have been solicited to coastal erosion problems, which have required the protection against this problem in two stages:

- To the 1990s: Five sites have been protected, namely: Ennajet, Echergui, Ouled Boua Ali and Mellita. The coastal protection structures were built with a similar design composed of an embankment in all coming and protected by a rock embankment. They are in total a linear of 3500 m.

- To the Year 2014: PPLT project (APAL, 2017): the project aims to protect the coastline of the Kerkennah archipelago against marine erosion. It includes:
    - The realization of a linear of rockfill jumper of 2130 m in Sidi Frej.
    - The realization of a linear of rockfill jumper of 800 m in Ouled Yaneg.
    - The realization of a linear of rockfill jumper of 2590 m in Bounouma.
    - The reinforcement of an existing jumper in Bounouma on a linear of 875 m.
    - The realization of a linear of rockfill jumper of 620 m in Ouled Kacem and Ouled Bou Ali site.
    - The realization of a linear structure in gabion of 675 m in Ouled Kacem and Ouled Bou Ali site; and
    - The reinforcement of a linear of existing jumpers of 1000 m in Ouled Bou Ali.

El Kraten: A rockfill jumper was built by the DGSAM on a 1300 m long coastline to protect the area from marine erosion.

Site of Djerba: During the years 1992 and 1993, several protective works of the type of rock embankments were established on the coast of the Djerba Island, especially on the north-eastern coast to prevent any advance of the sea near several hotels. Also, very short groins are built to protect the coast against erosion phenomena (Fig. 16).

- Hotel El Jazira: Longitudinal protection on 120 m.
- Hotel les Sirênes: Longitudinal protection on 170 m.
- Hotel Sidi Yati Midoun Club: Longitudinal protection on 60 m.
- Hotel Hari Club: 80 m of spikes.
- Hotel Laico: spikes of 90 m.
- Hotel Sango: spikes of 50 m.
- Aghir: Set of 8 spikes of 100 m each.

HoumetEssouk: Protection structures have been built by the DGSAM in HoumetEssouk:

300 m of a rockfill jumper.

200 m of palmivelle.

Figure 16. Southeast zone of Djerba (Aghir) protected by spikes

Site of Zarziss: North of the city of Zarziss, three coastal sites have been protected by a rockfill embankment, on a total linear of about 632 distributed as follows:

- On the sea front of the city: Longitudinal protection of 250 m
- In Beni Feteil: Longitudinal protection of 350 m
- In front of the Hotel Oamarit: Longitudinal protection of 32 m

III.3. Flexible methods adopted and implemented

Based on the observations made on the results of the solid structures carried out on the Tunisian coasts, APAL began, from the late 1990s, to find new flexible methods for the protection of coasts against coastal erosion.

However, the experience, in terms of concrete achievements, is still very limited. Indeed, it is limited to the techniques of stabilization of the top of the beach by forks and timid actions of beach recharging and stabilization by geo-tubes of sand (Fig.s 17-19).

III.3.1. Stabilization of the top of the beach with forks

The experience in Tunisia began in the early 2000s with the realization of a pilot action in Mahdia to protect the walkway of the city against marine erosion. Encouraged by the positive results of this first pilot experience, APAL has carried out other projects in recent years.

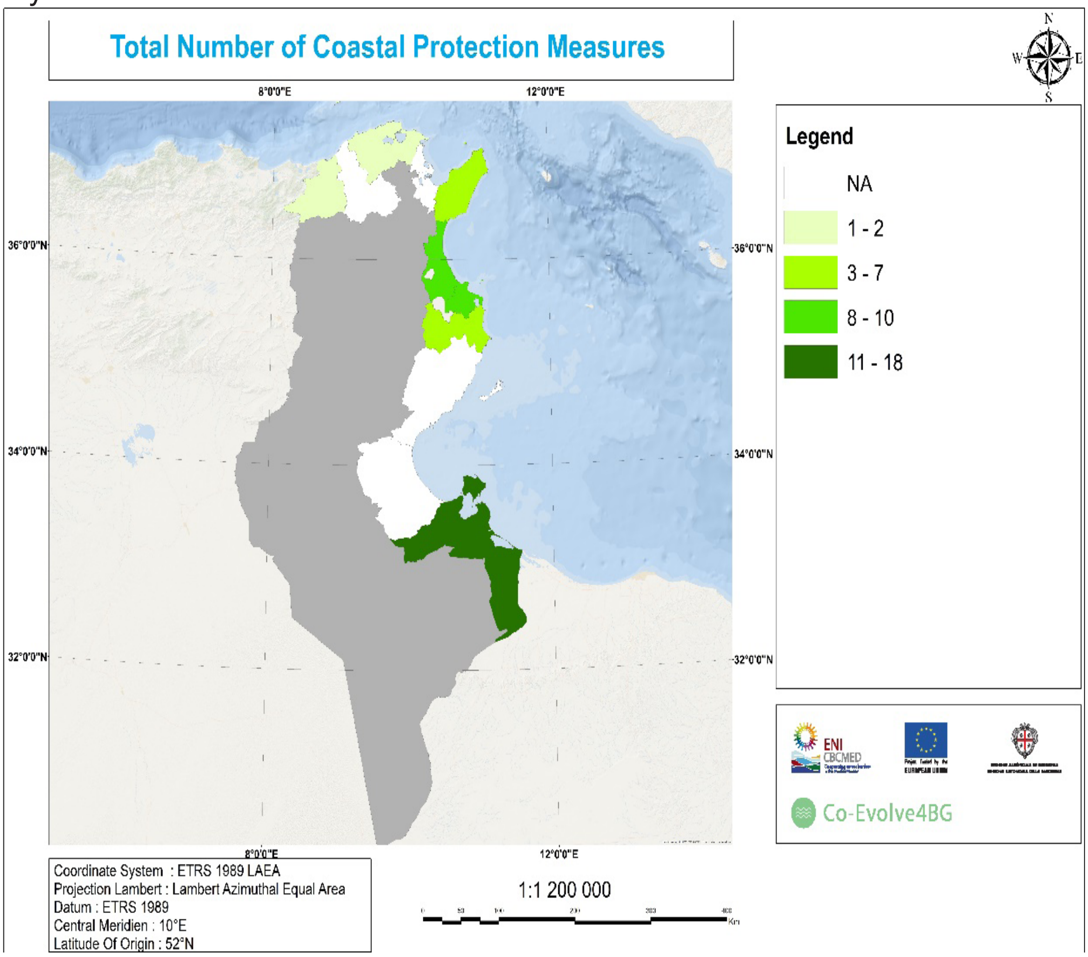

Figure 17. Coastal protective measures in Tunisia

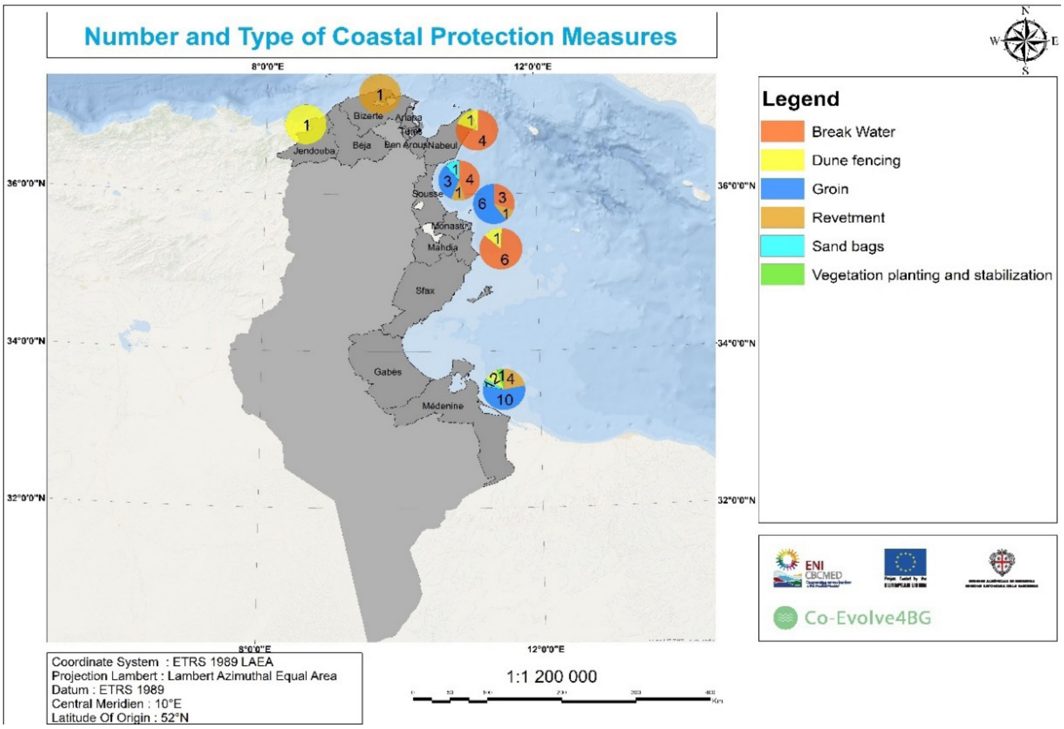

Figure 18. Number and types of coastal protective measures in Tunisia

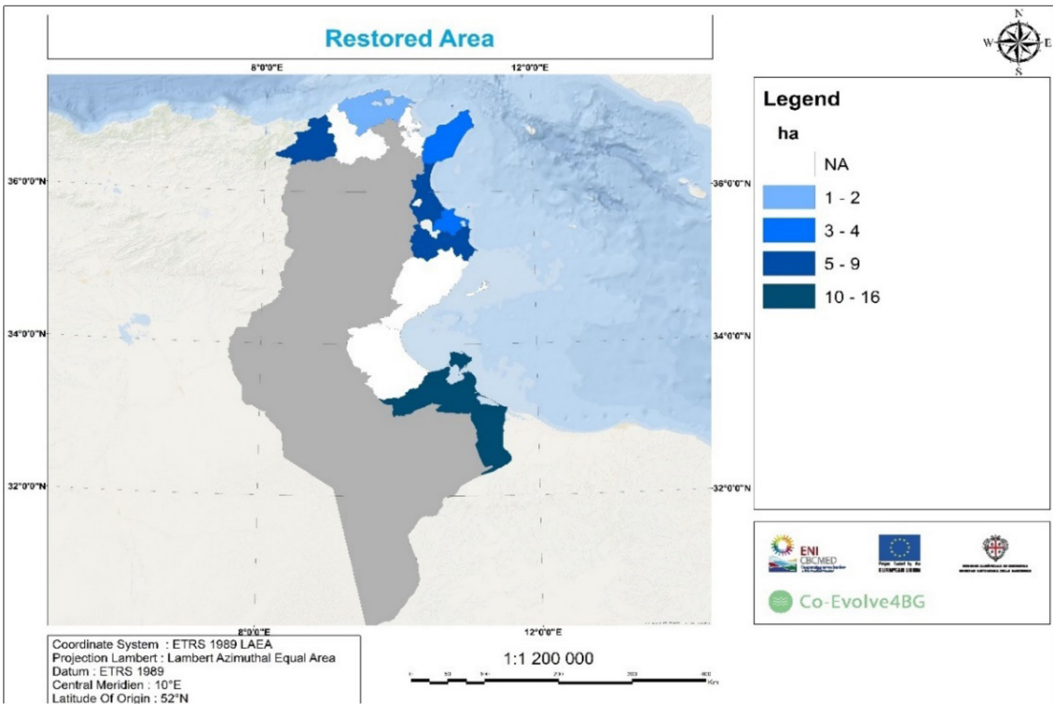

Figure 19. Coastal areas restored through protective measures in Tunisia

Table 1. Assessment of the Tunisian achievements in the field of stabilization of the top of the beach by forks

City	Location	Forks put in place m	Consolidated line of coastline m	Year of realization
Tabarka	Tabarka beach section	1,200	500	2019
	Section between the Mehari Hotel and Abou Nawas Montazah	1,850	250	2013
Korba1st tranche	Esplanade (northern part) and dunes along the lagoon of Korba	7,500	700	2005
Korba 2nd tranche	Esplanade of Korba	12,000	1,200	2012
BniKhiar	Beach south of the port of Beni Khiar	3,000	900	2012
Hammamet	--	--	1,000	2019
Mahdia 1st tranche	Beach of El Asfouria	2,700	1,000	2000
Mahdia 2nd tranche	Esplanade of the city of Mahdia	1,150	600	2013
Mahdia beach	City of Mahdia	1,150	600	2013
Sebkha Dimes	Between Monastir and Mahdia	--	700	2019
Chebba	Essir Beach in the city of Chebba	2,700	700	2013
Gabès	Esplanade of the city of Gabès	6,000	900	2013
Djerba	Beach of Sidi Hachani	1,600	280	2013
Zarziss	Sonia Beach	--	300	2019

III.3.2. Dune Restoration

Protection works against marine erosion, by a flexible method, of a section of coast from Sidi Mehrez to HoumetEssouk-Djerba were carried out in 2016 (DGSAM, 2014).

The solution of a reconstituted dune on the top of the beach will protect the residences from the crossing of the waves. It will favor a balance of the beach. This dune will be a sand reserve for the beach during bad storms. It will maintain the aesthetic appearance of the beach. The shoreline protection work includes:

Reconstruction of the dune for the northern section of 95 m length.

The reconstructed dune of the northern section will have the following characteristics (according to the cross-sectional plan file).

- Length of the segment to be developed: 95 m.
- Final elevation of the dune: +4 m NGT.
- Dune slope: approximately 3/2.
- Shoreline of the beach: +2.6 m NGT.

Reconstruction of the dune for the southern section of 80 m length.

The reconstructed dune of the southern section will have the following characteristics (according to the cross-sectional plan file).

- Length of the segment to be developed: 80 m.
- Final elevation of the dune: +4 m NGT.
- Dune embankment: approximately 3/2.
- Shoreline of the beach: +2.6 m NGT.

Figure 20. Example of soft method relating to the reconstitution of dunes by Posidonia, Action currently practiced in Djerba

III.3.3. Recharging of beaches

The method of Beach Recharging depends on the presence of an approximate field to recharge from it. The exploitation of a terrestrial deposit is not an evident solution given the large volumes necessary to mobilize. The quality of sand from land quarries does not meet, in most cases, the conditions required for the granulometry of the sand requested.

Until now, the Tunisian experience remains timid at this level. It has been reduced to the following specific actions:

Table 2. Beach nourishment actions carried out

City	Action	Quantity of mobilized sand m³	Linear of coastline reloaded m	Year of realization
Aghir - Djerba	Recharge of the beaches of the tourist area of Aghir from the sand deposited in the basin of the port	60,000	1,000	2000
Sidi Bousaid Tunis north	Rehabilitation of Sidi Bousaid beach by using the dredged products of the entrance pass of the nautical port	10,000	250	2001
Hammamet	Beach nourishment – to the south of the Hammamet marina from the sand dredged for the realization of the basin of the nautical port	120,000	300	1999
Djerba - Aghir	Periodic maintenance recharges made by hoteliers to feed their beaches from the sand trapped in the basin of the port shelters Aghir (Hotel Djerba Paradise. Club Med. Diva. El Kantra.*etc*.)	20,000	1,200 m/ year	From 2008
Raf Raf	Raf Raf beach nourishments to advance the coastline	500,000	2,000	2018
Soliman	Soliman Beach nourishments to advance the coastline	520,000	2,000	2018

Figure 21. Pilot project of recharging the coastline of Aghir (Djerba) in 2000

III.3.4. Stabilization with sand-filled geo-tubes

Until now, this method has only been practiced, in a very limited way, by two private individuals in Djerba.

Table 3. Stabilization actions carried out by geo-tubes

City	Action	Geo-tube length m	Linear of protected coastlinem	Year of realization	Cost DT
Aghir - Djerba	Stabilization of the beach of Djerba Paradise by a spike and two geo-tubes breakers filled with sand	80	400	2005	400,000
Sidi Hachani Djerba	Stabilization of the beach of the two hotels: Ulysse Palace and Atené Palace by two geo-tubes filled with sand	80	500	2008	700,000
Total		170	900	-	1,100,000

These two operations were not successful. For the first action, the structures put in place were destroyed after two months of their implementation. The second one is partially working, as a part of the infrastructure has been damaged.

III.4. Projected Programs

Projects are being studied for the protection of the coast against marine erosion. They include both traditional hard structure techniques and soft method techniques. Among these projects, it was mentioned in particular:

- Protection of the coastline of Cornice of Bizerte against coastal erosion: 6 km.
- Protection of the coastline of Chatt Mami against coastal erosion: 3 km.
- Protection of the section of the coastline at Cap Zebib-Governorate de Bizerte.
- Protection of the coastline in the northern suburbs of Tunis (Gammarth to La Goulette): 10 km.
- Protection of the Nabeul to Hammamet coastlines against coastal erosion: 18 km.
- Protection of the cornice of Nabeul.
- Protection of the Sousse-Monastir coastline from the Sousse commercial port to Skanes Monastir and the Karraya bay against coastal erosion: 16 km.
- Development and rehabilitation of the bay of Monastir: 12 km.

- Protection of the coastline of Rjiche-Salakta against marine erosion: 10 km.
- Rehabilitation of the coastal fringe “Plage Casino” of Sfax: 1 km.
- Protection of the sections of the coastline in Jebeniana – Sfax.
- Northeast coastline of Djerba: 9 km.
- Protection of the coastline from Aghir to Djerba against coastal erosion Aghir to Djerba: 7 km.
- Interventions and realizations of the flexible techniques for the protection of the coasts in the northern littoral of the Gulf of Tunis and the coast of the Djerba Island.
- Protection of the BniFeteiel coastline in Zarziss: Governorate of Medenine.

IV. Protective measures in tourist areas

IV.1. Importance of seaside tourism in Tunisia

Tunisia is considered one of the major tourist destinations in the southern Mediterranean. It welcomes on average more than 5 million tourists per year, accounting for about 17 million overnight stays.

The Tunisian coastline is home to more than 95% of the accommodation capacity and tourism activities in Tunisia. Key sector of the Tunisian economy, tourism has been very affected in recent years by political crises and terrorist threats. The sector contributes to the GDP to the order of 8% and covers nearly 51% of the deficit of the trade balance. Coastal tourism provides more than 400,000 direct jobs, most of them on seasonal contracts, according to official data and 286,200 indirect jobs. The tourism sector is considered one of the main contributors to GDP growth.

The tourist sector is largely oriented to seaside resorts with Tabarka, Bizerte, Tunis, Nabeul-Hammamet, Sousse-Monastir, Mahdia, Kerkennah and Djerba-Zarziss, with a total of 862 establishments (Fig. 22).

The impacts of beach erosion in touristic areas are already presented in Deliverable 1.

Figure 22. Location of seaside resorts in Tunisia

IV.2. Protection measures carried out and planned in tourist areas

The following table summarizes the measures carried out and planned for the protection of beaches against marine erosion in tourist areas.

Table 4. Protection measures carried out in tourist areas

Tourist zone	Measurements carried out		Measures in progress and/or planned	
	Solid protection	Flexible protection	Solid protection	Flexible protection
Tabarka	266 ml of a rockfill protection embankment 385 ml of a retaining wall	1,800 ml of Forks in front of El Mahari hotel	Submerged breakwater with a length of 410 m and a groin of 50 m Tabarka Beach Hotel	--
Bizerte	Cornice Bizerte 266 ml of an embankment of protection in rockfill. 385 ml of a retaining wall	--	--	--
North Tunis	--	--	--	--
Nabeul-Hammamet	Set of 4 breakwaters each in front of the Lido Nabeul hotel	Forks at the beach of Hammamet	--	--
Sousse-Monastir	El Kantaoui: groins of 80m long Sousse north: submerged breakwater of 1,600 m of total linear, 100 ml of the rider, 20 ml spur, Skanes: 620 ml breakwater, 450 ml groins. Cliff of Monastir: 2000 ml jumpers, 300 ml retaining wall, 200 ml submerged breakwater, 180 ml groins	Recharging of beach on a linear of 170 ml in El Kantaoui	--	--
Mahdia	Mahdia north: 820 ml breakwater	Forks	--	--
Kerkennah	--	--	--	--
Djerba	650 ml Jumper, 1000 ml spikes,	Geo-tubes, forks, reconstitution of the dune and palmivelles	--	--
Zarziss	632 ml rockfill jumpers	--	--	--

V. Conclusions

This bibliographic review has allowed us, in this deliverable, to present the main actions carried out to protect the beaches from the effect of marine erosion and SLR.

These achievements are summarized in the installation of coastal protection measures which can be divided into two groups: Solid structures and flexible techniques for coastal protection measures:

Solid structures for coastal protection: They are classified under 'Hard techniques. They aim to maintain the coastline or modify the evolution of its geometric configuration. These types of works began in the early 1980s by the implementation of rockfill structures for jumpers, groins, and breakwaters. The Program of Protection of the Tunisian Coast (PPLT) of APAL consisted in protecting 27 km of coastline against erosion and marine submersion by hard works (jumper, groins, and breakwaters) and flexible. A total of 46 km of coastline have been protected by this type of hard works.

Flexible coastal protection technology: APAL began, from the late 1990s, to seek new flexible methods for coastal protection. It has involved the techniques of stabilization of the top of the beach by forks. It also includes beach recharging and stabilization by geo-tubes of sand. Currently, a total of 10 280 m of coastline have been protected by forks distributed among the sites of Tabarka, Korba, BniKhiar, Mahdia, Chebba, Gabès and Djerba including of course the program PPLT of APAL.

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