Chapter 12
The Risk of Marine Erosion in Tunisian Beaches: A Retrospective Reading for a Prospective Vision

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Abstract Low coasts, especially sandy beaches, are the spaces that have, so far, attracted the most numerous and dense human concentrations and managements in Tunisia. They also correspond to the coasts that have suffered the heaviest damage from marine erosion.

This paper tries to come back on the main ideas developed by previous works concerning the characteristics, trends, and factors of beach erosion. The period considered spans about a century and a quarter of a century and should make it possible to identify lessons and evolutionary trends for better understanding and use of these coasts.

Based on such evolution and lessons, we try a classification of the different coasts containing beaches according to the risk of marine erosion in the current state and its consequences. The classification also considers the future implications of the current dynamics without losing sight of the potential vulnerability to the announced acceleration of the sea-level rise in the context of climatic change.

Keywords Tunisia · Coasts · Beaches · Marine Erosion · Retrospective · Prospective

12.1 Introduction

Beaches occupy a privileged place in the Tunisian coastal landscape, as they stretch along 550 km long. However, they are not everywhere relayed by dune fields. These take on a certain importance only along some 130 km of coastline (Oueslati et al. 2015).

Sandy beaches also correspond to the type of coasts, which have attracted the most numerous and dense managements and are the most affected by the risk of marine erosion. This has caught the attention of several researchers (Paskof 1985;

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Oueslati 1993; El Arrim 1996; Zeggaf Tahiri 1999; Khali 2001; Brahim 2001; Oueslati 2004, 2010; Bou Nouh 2010; Louati and Zargouni 2013; Marzougui and Oueslati 2017; Amrouni et al. 2019) as well as different departments responsible for land use planning and coastal protection mainly the Agency for Coastal Protection and Management (APAL). Its causes are both natural and human. However, an increasingly dominant responsibility is attributed to man's activity. The most delicate situations characterize the most anthropized sites. Unfortunately, this has increased over time and appears through repeated human interventions that have not always considered the requirements of a balanced evolution of beaches.

This paper aims to review the characteristics of the evolution over more than a century and its lessons. It also aims to retrace the main trends of the recent evolution and tries to draw attention to aspects still absent or poorly represented in the literature while they can be of great importance for understanding the risk of marine erosion and the challenges that beaches could face, mainly in the context of the predicted sea-level rise. Finally, we will try to draw up the current state of the various beaches and their classification by considering their situation facing a risk which will increase with the announced sea-level rise.

The results are based on previous publications and on various iconographic documents and official archives, often still little or not exploited. However, an undeniable place will be given to the contribution of direct observations in the field allowing data which escape the most commonly used documents (Fig. 12.1).

12.2 Beaches that Apparently Nothing Predisposed to Important Marine Erosion

Given the configuration of the coast to which they belong and the geology and the topography of the land bordering them, the beaches of Tunisia should not experience important marine erosion. They are often lodged at the bottom of gulfs, bays, and creeks, which generally constitute environments more favorable to the accumulation processes than to the wave's destructive action. In addition, the capes and promontories which frame them are often made of rocks that release sandy material. On the other hand, the bathymetry and marine hydrology are often weak over long coastal segments, especially on the country's eastern side and its southern part. Even on the northern facade, characterized by its relatively important bathymetry and its exposure to the strongest and most frequent winds in Tunisia, the waves are most often less than three meters in height, a value that is only exceeded during some storms. In the Gulf of Tunis, waves are only 1.5 to 2.5 m high in 6% of the cases observed, and waves greater than 2.5 m can miss several years in a row, as was the case, for example, during the period 1971–1980. Along the eastern coasts, the most frequent waves between Kelibia and Nabeul or at Sousse are, respectively, 0.70 m and 0.40–0.60 m high (Allenbach 1979; Italconsult 1973). Further south, wave energy

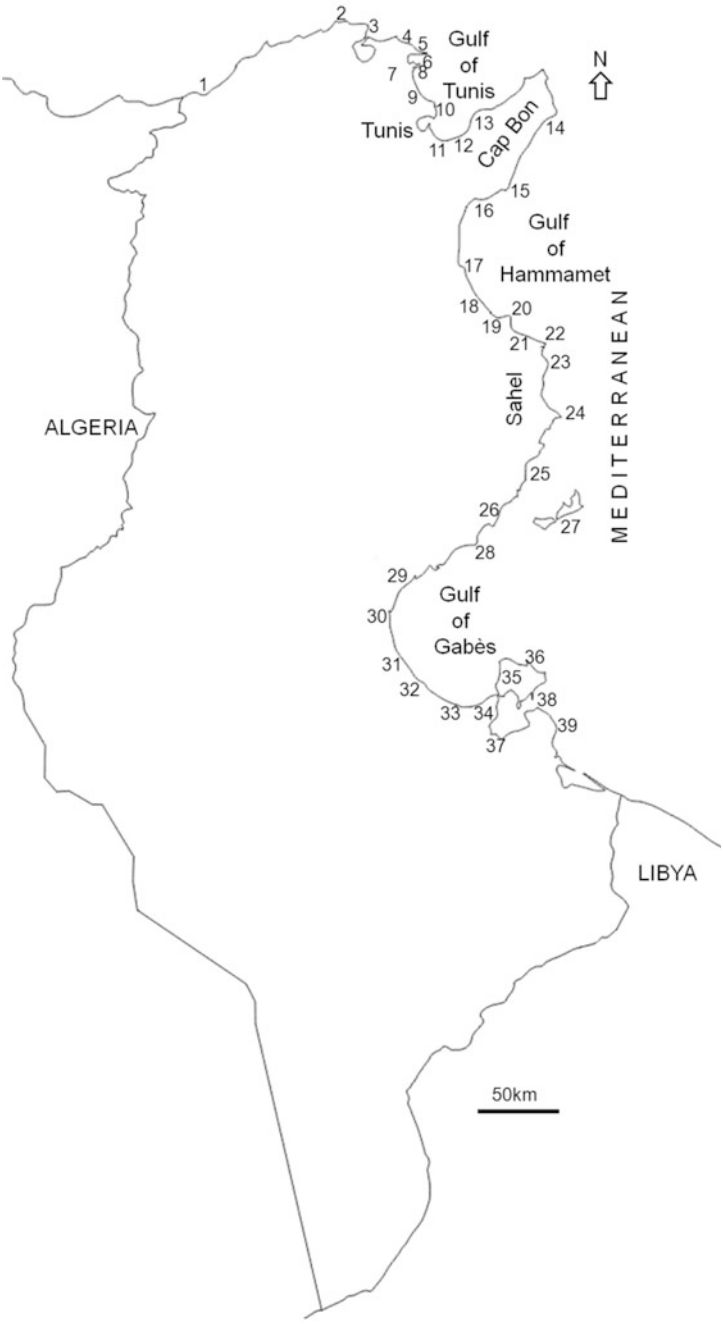

Fig. 12.1 Location of areas and localities mentioned in the text. 1. Tabarka; 2. El Ghirane; 3. Bizerte; 4. Rass Jebel-Beni Ata; 5. Raf Raf; 6. Ghar El Melh; 7. Utica; 8. Foum El Oued; 9. New mouth of Wadi Majerda; 10. North suburbs of Tunis; 11. Hammam Lif; 12. Sidi Ejjehmi-Soliman; 13. Korbous; 14. Kelibia; 15. Nabeul; 16. Hammamet; 17. Hergla; 18. Sousse; 19. Skanès;

is weakened in the shores preceded by extensive shallows occupied by important seagrass beds as in large part of the Gulf of Gabès and its islands.

The beaches of Tunisia should not also experience significant marine erosion because they receive a dense network of wadis known for their great erosive activity. This is favored first by the rainfall regime, which often leads to torrential, violent, and aggressive flows. It is also favored by the great extension of soft or mixed geological formations and the large areas which have suffered from land clearing and soil loosening works. In such a context, even the most modest wadis can have a high solid load on the occasion of certain rainfall events (Oueslati 1999). Therefore, the situation does not seem, in its natural state, to disadvantage the beaches in terms of sediment supply. However, some exceptions must be noted. They concern the lowest islands as well as the Sahel coast, devoid of a significant hydrographic network. They also concern part of the eastern coast of Cap Bon peninsula, the Gulf of Hammamet, and some segments of the Gulf of Gabès coast because the wadis do not always reach the sea. Some of them empty part of their load into coastal sebkhas, especially those blocked by a relatively thick barrier beach. Be that as it may, wadis brought have long influenced the behavior of different parts of the coastline. They were sometimes sufficient to push back the shore over long distances. The most expressive illustrations are associated with Wadi Miliane and Wadi Majerda, Tunisia's most important exoreic rivers. The displacement of the shore has sometimes been done over several kilometers since antiquity. In the case of Wadi Majerda, this is witnessed by the position of *Utica* ruins. The port of this ancient city, which continued to function under the Roman occupation, is now more than ten kilometers inland (Jauzein 1971; Paskof 1985). However, significant illustrations even exist at the mouths of modest rivers, especially in coasts characterized by weak bathymetry. The wadis brought have sometimes led to alluvial fans or plains, sometimes extensive and well-marked in the coastal landscape. This is the case for wadis which open into the lacustrine system of Bizerte (Oueslati 1995). It is also the case at the mouth of the wadis Chaffar and Lben in the Gulf of Gabès or the wadi El Fjé, even more modest, which open into Boughrara bay, opposite Jerba Island. In this last case, large alluvial fans, particularly well-marked in the coastal landscape and on aerial photographs or satellite images, are much more recent. They have appreciably been confirmed, thanks to the large sediment volumes during the two major pluviometric events of autumn 1969 and January 1990 (Kouka 2015).

As for the sediment contribution from the open sea, we do not have precise information. However, observations made on some beaches after intense storms brought quite interesting data. This was the case, for example, in the beaches of Sousse the day after the strong storm that occurred in March 2012. Beaches that have lost a large part of their substance or have been totally eroded were naturally

Fig. 12.1 (continued) 20. Monastir; 21. Khnis-Sayada; 22. Rass Eddimess: 23. Mahdia; 24. Chebba; 25. Melloulèche; 26. Sfax; 27. Kerkena I.; 28. Chaffar; 29. Skhira; 30. Bou Said; 31. Oudhref; 32. Gabès; 33. Zarrat; 34. Jorf; 35. Jerba I.; 36. Rass Errmal; 37. Boughrara; 38. Dhar Ghannouche; 39. Zarzis

reconstituted. Several of them found their initial width by July of the same year. This reconstitution can not be explained by terrigenous or by lateral sedimentary inputs, because the small wadis that flow on this coast are strongly managed and the region had not recorded significant rains between March and July. On the other hand, these beaches are cut off from the neighboring coasts by various obstacles drawn upon the path of the littoral drift. A large part of the sediment was actually pushed from the open sea, consequently to the destabilization of the seabed sediments caused by significant destruction, during the storm, of the marine vegetation (Oueslati 2016).

12.3 A Risk Not Limited to Managed Coasts and Perceived for More than a Century

12.3.1 Various Evidences and Indicators

Despite the unfavorable natural context for important marine erosion, as demonstrated above, several beaches have lost an important part of their natural substance or have completely disappeared even in sheltered sites of area characterized by shallow water and weak wave's energy. This began to occupy an important place in the scientific literature in the last quarter of the twentieth century and was often treated as if it was a new phenomenon. Moreover, protection efforts within the framework of major interventions supervised by the state began after the 1980s following the heavy damage caused by strong storms that occurred in January 1981 in the Gulf of Tunis and on the coast of Sousse (Fig. 12.2).

However, the problem has started for over a hundred years as evidenced by different documents. Among the last are postcards which circulated during the first half of the twentieth century, in the 1920s and even the 1900s. Some of these photos show beaches that have become very narrow and sometimes crossed by many alignments of wood groins (Fig. 12.3). The same idea is found in various archival

Fig. 12.2 (**a** and **b**) Hammam Lif beach, in the Gulf of Tunis: the situation the day after the storm of January 1981 and the situation today (photos, Ameur Oueslati). The breakwaters shown were installed in the 1980s and correspond to the first intervention by heavy protection structures in Tunisia. The arrow indicates the same trees

Fig. 12.3 One of many postcards from the first half of the twentieth century showing the narrowing of the beaches in the northern suburbs of Tunis and the wood groins (the original photo is owned by the author)

documents and in newspaper articles. Certain archives like those of the municipalities of the northern and southern suburbs of the city of Tunis evoke damage mainly in the occasion of storms like that of January 1951. Other documents from the same archives indicate that the recourse to wood groins, for example, had already been practiced at least since 1916 (Khali 2001). For its part, the press has often mentioned the problems facing seafront properties. This has become quite frequent especially since the period between the two world wars. Some articles also reveal an important perception of the problem by the local population and report that petitions have been addressed on various occasions to the authorities, by the dwellers of the shores at risk (Khali 2001). Everything indicates that it is in the oldest developed coasts that the manifestations of beach erosion were the first. This is valid even in the shores with little exposure and coasts preceded by a low bathymetry as in the city of Sfax (Fig. 12.4). The most eloquent illustrations, however, belong to the suburbs of Tunis.

The aforementioned documentation only provides information on shores that were the first to attract managements. This could suggest that erosion is caused by man. However, the observations that we have been able to make on coastal segments different by their location and their management indicate that the phenomenon is also part of a natural trend. In the region of El Ghirane west of Bizerte, for example, a blockhaus dating from the period of the Second World War (Fig. 12.5) has been for several years, before the recent appearance of second homes in the area, directly beaten by the waves and completely surrounded by marine water during storms. However, when it was set up, it must have occupied a position behind the beach in the middle of the dunes that border it (Paskoff 1985; Oueslati 2004). It should be

Fig. 12.4 Sidi Mansour coast; North Sfax; photo taken by low tide. Part of the dwellings is yet abandoned (example indicated by the white arrow) (photos, Ameur Oueslati, Nov. 2017)

Fig. 12.5 Blockhaus at El El Ghirane, annexed to the foreshore area. It owes its conservation to the fact that it rests on a resistant substratum. Originally, it must have been in the dune area. (photo Ameur Oueslati, July 2015)

noted in passing that in the coastal segments devoid of resistant bedrock, constructions of the same type have often been annexed to the sea and are sometimes found several decameters in front of the shore. Some of the most eloquent examples can be found on the coast of Sousse (Oueslati 2004). In other cases, also away from

Fig. 12.6 South to Melloulèche (between Mahdia and Sfax): the importance of marine erosion sometimes forced the displacement of coastal tracks. However, the coast is characterized by the weakness of its bathymetry and still away from seafront managements (photo, Ameur Oueslati, Nov., 2017)

managed areas, one can see on the foreshore outcrops of materials that were originally deposited behind the border dune. The latter is in such situations always truncated by an active cliff. This indicates a migration of the entire coastal sedimentary prism. Illustrations have been described between Soliman and Sidi Rais in the bay of Tunis and at various points on the eastern coast of the Cap Bon peninsula (Oueslati 2004). Expressive examples are also found further south, in coasts much less exposed to swells and in environments, like the Gulf of Gabès, logically unfavorable to significant marine action. This is the case, for example, in a large part of the coast between Chebba and Sfax, especially south of Melloulèche (Fig. 12.6). Here, the shore recedes everywhere, sometimes at a rapid speed as indicated by the repeated displacement of the coastal track and the state of the vegetation frequently severely bare at the top of the beach. Significant illustrations also exist in the beaches, often narrow and discontinuous, in the coast which stretches south of Mahares to the surroundings of Skhira (Fig. 12.7), in the coast situated between Bou Said (Fig. 12.7) and Ouedhref north of Gabès as well as in the southwestern part of the peninsula of Jorf, in most of the coast of the Kerkena archipelago, and on the marine face of Slob Echchergui near the Libyan border (Fig. 12.8). All these beaches are still away from managements that could disrupt the coastal dynamics. In addition, they are frequently preceded by a very low bathymetry and sometimes by important shoals.

Fig. 12.7 The state of the coast at Bou Said (South Skhira), in an area far from all human intervention. The beach has become very narrow, the foredune is truncated and its vegetation bare (photo Ameur Oueslati, Oct. 2018)

Fig. 12.8 On the eastern face of the Slob Echchergui (near the Libyan border), an area equally far from all human interventions, beaches are undergoing a severe erosion. As in the case of the coast of Melloulèche, the state of the vegetation and a coastal track give the measure (photo Ameur Oueslati, Nov. 2017)

12.3.2 What Conclusions?

The above may authorize some essential conclusions. On the one hand, beach erosion is part of a natural trend since its effects manifest even in areas away from direct or indirect human intervention. Man has in reality only accentuated a phenomenon already operating in a natural state. On the other hand, the fact that this erosion began by attracting attention in the managed beaches testifies, in addition to the vulnerability of these milieus, to the importance of waterfront managements as benchmarks and revealers of beaches' actual condition. Indeed, the regressive trend of a beach often goes unnoticed in the absence of directly threatened properties. This can mislead planners; a wide beach is not necessarily immune to all risks.

The fact that beaches are endangered in their existence in the absence of human intervention must logically be seen as an essential sign of a change in environmental conditions since these forms are, by definition, the result of dynamics in which the accumulation processes predominate. In any case, the sediment inputs must exceed the volume of the outputs. Such situation which prevailed in the past seems to be over along the major part of the Tunisian coasts. This would confirm the idea, known since the 1980s (Bird 1983), of a shift from a situation of abundance to a situation of sediment scarcity on coasts. However, the data available for the Tunisian coasts does not allow a clear opinion on the causes of such an evolution. The only indicators that can be mentioned with some certainty are related to the sea-level behavior and the stability of the coastal soil. The situation is most delicate in the fields that experience conjunction between the negative effects of the two factors. This is particularly the case in the Gulf of Gabès, especially in its northern half characterized by active subsidence that accentuates the impact of a sea-level rise recorded after antiquity and continues today (Oueslati et al. 1987; Slim et al. 2004). Such an idea is supported by the existence of numerous submerged ancient archaeological remains in this area. The submersion often exceeds 1 m and locally reaches 2 m, like in the Kerkena archipelago, while it is only 20–40 cm in the other parts of the Tunisian coasts considered as tectonically stable (Slim et al. 2004). The same idea is also supported by tide data, the compilation of which allowed to conclude to a relative positive sea level variation four times faster in the port of Sfax, situated in the Gulf of Gabès, than in the ports located further north (Pirazzoli 1986). This actually expresses the effect of the conjunction of the eustatic sea-level rise and subsidence (Oueslati 2021). We can then understand the rapid erosion of several beaches of the Gulf of Gabès and the coasts that extend it towards the border with Libya, evoked above, despite their location away from urbanized spaces and their belonging to shores sheltered and outstripped by weak bathymetries.

12.4 An Inexorable Growing Risk, Especially Since the 1980s

12.4.1 A Growing Human Responsibility

In the first decades of the twentieth century, beach erosion attracted attention only on the shores of the northern suburbs of Tunis. These shores were the first to experience an increase in the number of built-up coastal areas. The time factor is important. In general, the manifestations of erosion are, in a given site, all the more apparent the older the management. This also consists of the first proof and manifestation of man responsibility in beaches' erosion. The error came from the fact that buildings were often located very close to the sea, regardless of the width and the state of beaches. This led to disturbances in the sediment dynamics and the exchange between the different parts of the transverse profile of the beaches and the foredunes. Such a

Fig. 12.9 Example of a foredune leveled to allow an open view on the sea; beach of the Ismail hotel in Tabarka (photo, Ameur Oueslati 2004)

dynamic is, as is well-known today, of capital importance for beaches' balance and their adaptation to sea conditions. We also know the importance of the foredune mainly during the difficult moments that a beach can face, such as during storms. It constitutes a vital sedimentary reserve and acts as a screen against the strong waves and the flooding of the lowlands which relay it. Unfortunately, this has been very often overlooked. In addition, other weakening practices have been added over time. Even when it escaped the concrete, the foredune was sometimes razed just to allow the occupants of certain constructions to have a view of the sea (Fig. 12.9).

The multiplication and densification of waterfront hard constructions can only accentuate marine erosion and extend it to increasingly long coastal segments. Such an evolution has been confirmed over the last decades, especially with the significant development of seaside tourism in the 1980s. Before that date, the perception of the seashores by the Tunisians was quite different. Many newspaper articles, sometimes dating from the beginning of the twentieth century, relate the attraction of Tunisians to the beaches (Oueslati 2004). But there was no obsession with building feet in the water. Except in the towns that have welcomed a large European community, the inhabitants have rarely opted for a permanent dwelling on the shore, even in coasts with extensive beaches. Rather, a significant distance was kept from the sea to avoid soil moisture and wind sand. Many expressive illustrations of the recent change in perception of the coast as a result of the development of tourism were described as well in small towns such in the Cap Bon peninsula (Korba, Menzel Temime, Tazarka, etc.) and in the Sahel (Rejiche, Salakta, etc.) as in large cities like Nabeul and Gabès (Oueslati 2004, 2010). The island of Jerba also offers a particularly expressive illustration. Its eastern coast, which is entirely made up of sandy beaches and expands over 40 km, remained almost deserted until the 1970s. The rare constructions that one found are some marabouts inherited from times of insecurity

experienced by the island. This coast's first hotel (El Jazira) was built in 1958 (Paskoff and Miossec 1979) and will remain isolated until the 1970s. Today, apart from the spits of Rass Errmal and El Gastil, this coast is heavily occupied and counts hundreds of hotels. In fine, even in Tunis, a large part of the beaches, especially in the southern suburbs between Rades and Hammam-Lif, would have remained unbuilt, at least for a good portion of the twentieth century in the absence of the French colonization.

In recent decades, practices that have harmed beaches and increased the risk of marine erosion have multiplied and diversified. The interventions which had the most impacts on the dynamics and the sediment budget took place both inland and on the shore. Inland, varied managements have reduced terrigenous inputs to the beaches. They consist of a multitude of dams as well as different water and soil conservation works in the watersheds of a large part of the exoreic wadis. Their consequences were felt most in the beaches of the northern and central parts of the Gulf of Tunis, which receive the two largest exoreic rivers. However, even in smaller streams on the east coast, the effects were sometimes startling. The situation at the mouth of Oued Chaffar south Sfax gives one of the expressive illustrations. The creation of a dam and the multiplication of obstacles in the watershed of this wadi have caused an unprecedented acceleration of the erosion of the beach (Fig. 12.10).

12.4.2 An Erosion at Rapid Pace

Many publications have tried to quantify the displacement of the shore consequently to marine erosion (El Arrim 1996; Louati and Zargouni 2013; Brahim 2001, Oueslati 2004; Bada 2017; Marzougui and Oueslati 2017; Amrouni et al. 2019). Much of the quantification results were based on documents of different dates (topographic maps, aerial photographs, and satellite images). Among the many values, we mainly consider in this work those obtained for long coastal stretches allowing to take into account different factors in action and those covering periods sufficiently long to reveal a clear evolution trend. However, the results obtained for specific short coastal segments or relatively short periods are sometimes significant. They deserve to be mentioned as they can reflect the specificities of some particular environments or the critical impact of specific management or events.

The first quantification attempts, carried out until the last years of the twentieth century, did not always use methods and software allowing precise control of the margins of error in the results obtained. However, the available results are not devoid of interest with regard to the long periods often covered by the documents and the critical change experienced by some beaches. Four main coastal segments, containing long beaches, have been mainly concerned: the Gulf of Tunis, the Gulf of Hammamet, the eastern coast of the island of Jerba, and the coast of Mahdia. A first summary (Oueslati 2010) of the data obtained for the last three decades of the twentieth century confirms the general trend marked by the retreat of the shore. This was often done at a speed varying between 0.5 and 2 m/year and has sometimes

Fig. 12.10 The state of the beach and the recent constructions a few hundred meters from the mouth of Oued Chaffar: the comparison of the photos is revealing as to the significant reduction in the width of the beach and the rate of the shore retreat (Photos, Ameur Oueslati)

reached 5 m/year. Higher values are reported by studies devoted to limited areas and over short periods. Most of them are in fact obtained for sites whose sedimentary dynamics have been brutally disturbed by port managements. The maximum value was recorded in contact with the fishing port of Ghar El Melh, in the north-western part of the Gulf of Tunis. The beach cut off from the inputs of the coastal drift retreated, from 1974 to 1976, from 90 to 100 m on a stretch of coast 560 m long (El Arrim 1996). Important values were also obtained for coasts which have suffered the effects of strong sea storms such as the beaches of the bay of Tunis following the storm of January 1981, mentioned above. A large part of the beaches, sometimes several decameters wide, but bordered by hard constructions, were washed away in the space of a few days.

More recently, the quantification of shoreline mobility from cartographic, photographic, and imagery documents has benefited from increasingly sophisticated

computer tools and software. The results obtained are more precise and confirm the general trends identified by previous publications. However, they often report higher values suggesting an increase in the risk. A study (Bada 2017) covering the entire Gulf of Hammamet, the eastern side of the Cap Bon peninsula, and part of the Sahel coast has shown that a large part of beaches is eroding. Shoreline retreat has fluctuated through time but with a tendency for acceleration in urbanized areas. Shoreline retreat reached in different sites values between 4 and 6 m/year. The highest values were recorded in the beaches bordered by dense constructions or cut off from the contributions of the littoral drift. Other studies have been devoted to the beaches located on the front of the Oued Majerda delta and at the bottom of the bay of Tunis (Louati and Zagrouni 2013; Marzougui and Oueslati 2017). The results also confirm an accentuation of the rate of erosion, especially in the beaches bordered by hard buildings. They also confirm the extension of the risk in parallel with the extension of the building along the shore. Beaches that until recently had been spared this risk have sometimes become among the most vulnerable. This is particularly the case of the beach stretching between Sidi Ejjehmi and Soliman in the eastern part of the bay of Tunis. In its natural state, this beach corresponds to a united sediment cell and was largely outside waterfront managements until the 1990s. Since then, the situation has changed dramatically, and the area has quickly become one of the most threatened by marine erosion. The rate of the shoreline retreat over the last decade has often exceeded 4 m/year and sometimes reached 7 m/year. As we will see later, this erosion started with the first waterfront constructions and has been then accentuated by unsuited protective works.

It should finally be noted that the results drawn only from cartographic, photographic, and imagery documents can sometimes be erroneous. A recent work (Amrouni et al. 2019) applying a photogrammetric assessment on documents covering a part of the Gulf of Hammamet for the period between 1887 and 2018 concluded to a regressive evolution accentuated by urbanization. The idea as such is in concordance with the results of previous works. However, some of the advanced values cannot convince, because, returning to the field truth, some of these values seem doubtful, even inconceivable. For example, we cannot admit that at the level of the central and southern parts of the town of Hergla, the shore was in 1887 behind the current one and that it has since moved over several decameters towards the sea. Quite simply because the morphology is that of a cliff more than 10 m high, cut in a Plio-Quaternary clay-sandy formation and crowned by a thick and resistant limestone crust. The land cannot gain ground over the sea when the shore corresponds to an active cliff. Likewise, in the northern part of the study area, the 1887 shore is placed by the authors in the sea more than 150 m ahead of the ramparts of the Medina of Hammamet, while none of the nautical charts of the end of the nineteenth century can confirm it. This Medina has long been known for its proximity to the shore; its ramparts also appear in contact or at a short distance from the sea on postcards and drawings dating from the beginning of the twentieth century. In fact, we are in the presence of one of the illustrations of the limits of the results obtained by works carried out on the basis of the only manipulation of documents, even if it is by sophisticated computer tools. Monitoring the evolution in

the field always provides important additional information and can even lead to interpretations in total opposition to those based solely on documents. Some illustrations will be given through the following case presentation.

12.5 The Documents Do Not Reveal Everything and Can Sometimes Mislead

The results obtained thanks to the various documents mentioned above have allowed first insight as to the shore mobility. This is important for the assessment of risks due to marine erosion. However, it does not capture all the components of the problem. Indeed, the width criterion is not the only indicator of beach vulnerability. The thickness of sediments is also essential.

On the other hand, the width observed in satellite images and aerial photos does not always reflect the width established by natural dynamics, especially in anthropized areas. This can be significantly changed by the owners of the waterfront properties. No less critical, the documents mentioned above do not always allow us to identify the effects of exceptional events. The vulnerability of beaches and the marine erosion risk are indeed often revealed during some storms. Finally, the documents do not show the behavior of the threatened property owners, which is essential for understanding the public's perception of the risk. Hence, information accumulated through direct observations in the field over a sufficiently long period can help fill in such gaps and provide elements essential for assessing the risk in its various components.

Unfortunately, the cases of beaches for which we have, in addition to the above results of the exploitation of documents, data acquired thanks to direct field observations over relatively long periods have remained few. Moreover, the protection works have, in many cases, interrupted the monitoring process. The use of hard structures has multiplied in parallel with the multiplication of sites concerned by the risk of erosion. It sometimes started at early dates, which makes the accumulated data just archival ones. Such an evolution applies to a significant part of the southern coast of the Sousse agglomeration and especially to a large part of the coast of Tunis. These coasts were, as evoked above, the first to undergo significant protection works after the damage caused by the exceptional storms of January 1981, so that the most recent photos showing their natural beaches date back to more than 30 years. The problem of information discontinuity due to protection works also arose, but at a more recent date, for several shores such as those of Kelibia, Mahdia, or Chebba and Sfax. In other situations, the natural dynamics of the beach was blurred by the backfill of the foreshore (Taparura Project in Sfax, Marina of Bizerte; Khnis-Ksibet El Mediouni coast near Monastir, Ben Ghayadha project in the south coast of Mahdia, etc.), the creation of waterfront roads (between Lamta and Eddimess in the Sahel), and the accumulation of dredging products (Radès-La Goulette, Sayada, etc.) or urban and industrial discharges (Sfax, Gabès, etc.). Nonetheless, beaches

where the monitoring of the evolution of the position of the shoreline is still possible or has continued to be possible until the very last few years exist yet. This is particularly the case in the towns of Tabarka and Bizerte, in the vicinity of Rass Jebel, in Raf Raf, on the coast of Nabeul-Hammamet, in Sousse North, in Mahdia North, in Chaffar situated south of Sfax, in Gabès, and in Jerba Island.

In the following paragraphs, we present two cases belonging, respectively, to the country's north facade and the east facade. These cases are also chosen for their expressiveness about the importance of the risks associated with marine erosion but also for the insights they can provide on certain phenomena and data that may escape work based on the interpretation of documents and that only repeated observation of the field could allow.

12.5.1 The Corniche Beach of Bizerte

This beach stretches between Cap Bizerte and the marabout of Sidi Salem over a length of about 4 km. It began to be occupied by waterfront constructions relatively early, under French colonization. However, a clear distinction must be made between its northern and its southern half.

The northern sector contains the oldest managements and was the first to show the manifestations of wave destructions. This has been mentioned at least since the 1970s (Mathlouthi and Paskoff 1981; Oueslati 1993). A wall was built to protect the coastal road occupying the site of the foredune. Since then, and depending on the state of the sea, a beach rarely wider than 15 m has reconstituted or disappeared. The wall itself has given way and been rebuilt on various occasions. The last time this happened was in November 2019, following an ordinary storm.

Near the Petit Mousse restaurant, in the southern part of this sector, dwellings dating from the colonization period have not benefited from protection which allows a better appreciation of the effect of marine erosion. All the constructions were severely damaged and have lost the entire beach to which they had come to seek proximity. In addition to the shore retreat revealed by various aerial photography missions, direct field observation concludes a vertical lowering of the beach surface, at least several decimeters. This is evidenced, for example, by the steps of the doors overlooking the sea, which have become perched. The owners then resorted to the construction of stairs, some of which in turn became perched (Fig. 12.11). One of these stairs is now suspended more than a meter and a half above the foreshore. Here, we have the expression of one of the crucial modalities of the beach regression that a work limited to the exploitation of documents does not allow detection or measure.

The southern sector, up to the Ain Mariem hotel, is the one that attracts the most attention today because of the sudden change in the behavior of its beach. Safe from marine erosion until recently, this beach has been severely damaged and more and more aggressively attacked by waves. The signs of fragility first started in its northern part. Further south, the coast of the Residence of Ain Mariem has remained wide and thick until the middle of the first decade of this twenty-first century. Its

Fig. 12.11 The situation at the Corniche de Bizerte, in the vicinity of the Petit Mousse restaurant: the state of the stairs, witnesses of the important lowering of the surface of the beach (Photo, Ameur Oueslati, April 2010)

width, which we measured on different occasions during the 1995–2005 period, has always varied between 70 and 90 m (Fig. 12.12a). Such situation was explained by the hydrographic context: mainly the existence, about 700 m offshore, of an important shoal (Bou Barrek) lying parallel to the coast and playing in a way the role of a natural submerged breakwater (Mathlouthi and Paskoff 1981). However, the persistence of a wide beach until very recently despite a multiplication of managements since the 1980s could also have links with the evolution undergone by the previous sector. The coastal drift, mainly directed towards the south, has long had an important contribution by the sediments torn from the beaches situated further north. The last having been completely eroded or almost, a new conjuncture took hold, so much so that we are in a situation which may, in a certain way, recall the phenomenon of sedimentary wagons. In any case, everything suggests that the risk of erosion has, over time, increased and moved towards the south in the whole Corniche beach. The big beneficiary is the beach of Sidi Salem located further to the south where it leans against the long jetty of the front port of Bizerte.

The situation has deteriorated in this second sector, particularly since the beginning of the 2010s. Marine erosion has already washed away most of the beach, and the constructions overlooking the sea were sometimes severely damaged. Today, the Ain Mariem hotel and the Jalta one situated immediately north are protected by

Fig. 12.12 The evolution of the beach between Ain Mariem and Jalta hotels in the space of 20 years (1999–2019) (photos, Ameur Oueslati). (**a**) The beach in 1999; (**b**) disappearance of the beach and formation of a small cliff showing allogenic materials on the sand of the beach and the foredune; (**c**) the situation towards the end of a storm in November 2013; (**d**) the current situation; the place is given to protective structures

riprap dikes (Fig. 12.12d). Before the implantation of these structures, the waves have regularly, especially during storms like that of November 2013 (Fig. 12.12c), shaped small cliffs in the material occupied by the hotels and their external gardens (Fig. 12.12b). The sections reveal the witnesses of practices that have been condemned by various researchers long before the occupation of this part of the Bizerte coast. Indeed, everywhere the sections show the sand of the beach and the foredune covered by various and sometimes harmful materials (landfill products, remains of construction sites, etc.). We also guess that the beach and dune material was used in construction sites because the sections show the sand only over a minimal thickness. In contrast, the old aerial photographs and the morphology of the sectors still not yet built indicate undeniable foredune.

12.5.2 The Case of the Skanès Coast

This coast is comprised between the mouth of Oued Hamdoun and the Monastir peninsula. It is some 11.5 km long and corresponds to a bay occupied by sandy beaches relayed by a small dune field punctuated by palm trees. Until the 1980s, its

dune space was exploited by vegetable gardens devoid of solid constructions. The former Presidential Palace, located at its eastern end, was the only significant building. Today, the major part of this coast is covered by hotels and various tourist facilities.

On the eve of tourism development, the beach had a width varying from 20 to 90 m and was the most extensive in the central part of the bay. It enjoyed a sediment supply ensured mainly by a littoral drift that runs in two directions. The first runs East carrying a part that Oued Hamdoun brought. The second comes from the East and pushes the sediments torn from the cliff of Monastir. The foredune is modest by its height (2–4 m) but relatively wide (30–120 m) and forms a continuous ridge well-marked in the landscape. It was not, however, a coast immune to erosion. In the early 1990s, different weakness forms or even shore retreats were already described, especially in the western sectors (Oueslati 1993). Among the indicators are remains of ancient constructions unearthed in the outer part of the beach. No less significant is that some palm trees were reached by the shoreline and sometimes surrounded by water during storms. In the area now occupied by the Chems hotel, the regressive trend of the coast appeared through a blockhaus inherited from the period of the Second World War. According to aerial photos of the 1974 mission, this blockhaus was separated from the sea by a 29.5 m wide beach. The observations and measurements we made directly in the field show that it began to be reached by storm waves since the mid-1990s. The beach was still 9.5 m wide in 1995 and disappeared by 2002. The blockhaus, then regularly scoured at its base, was already in 2004, tilted towards the sea. It has been intentionally destroyed later. The regressive trend in this western sector of the bay has also been attested by a diachronic analysis of different documents (Bada 2017). The shore receded at a speed of 0.7 m/year to 1.2 m/year between 1962 and 1996 and from 0.8 m/year to 1.2 m/year between 1996 and 2010.

The situation has exceptionally deteriorated over the last decade, especially in the western sectors. Almost all of the beaches that have hosted hotels have lost most or all their natural material. Such evolution is due to the reduction of the sediment supply ensured by the coastal drift due to the construction of the dikes of the port of Sidi Abdelhamid basin on the west side and the installation of breakwaters and groins on the eastern side at the level of the presidential palace and the cliffs of the Monastir peninsula. However, the evil came mainly from the proliferation of hard seafront constructions which cut the beach from the dunes. To this were added the effects of other practices or of some natural events which cannot be grasped on photographic or imagery documents. This is mainly the case of works modifying the profile of the beach by an artificial redistribution of its sand. It is also the case for particular storms.

Regarding the modification of the profile of the beach was sometimes practiced from the first days of hotel creation. The goal is to maximize the sandy surface made available to customers. This was done by leveling the foredune and spreading its material towards the sea. Such artificial widening of the beach can be misleading if one limits oneself to an analysis of the shoreline evolution on the basis of the documents. Moreover, a small dike (*tabia*) using the dune sand or allogenic material is generally created between the hotels and the beach and can be moved as the shore

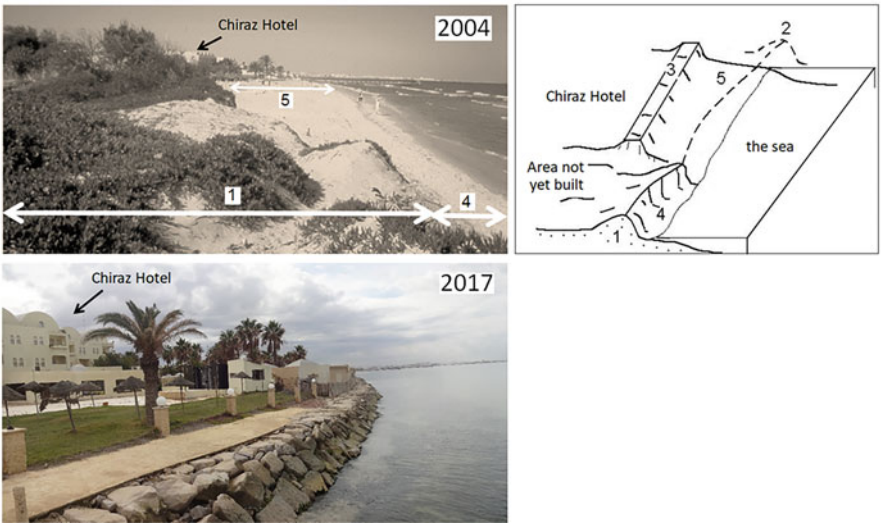

Fig. 12.13 Reshaping of the beach at the Hotel Chiraz and the evolution after: 1. foredune in the initial state; 2. part of the beach and the foredune destroyed when the hotel was set up; 3. *tabia*; 4. initial width of the beach; 5. width of the beach obtained after leveling the foredune. The goal was to expand the beach surface offered to hotel guests. But the counterpart was a weakening of the beach. The 2017 photo testifies to this, a storm swept over the beach and forced the use of protection by a riprap dike (photos, Ameur Oueslati)

recedes. Such a practice permitted the expansion of the beach, but it has gradually reduced its thickness, making it increasingly vulnerable to erosion and submersion by waves. In other cases, the buildings have kept a certain distance from the sea, but the dune space that separates them from the beach has been leveled and transformed into gardens and areas to construct large swimming pools. Photos taken on various dates at the Chiraz and Houda hotel summarize some of such practices (Figs. 12.13, 12.14, and 12.15).

As for storms, they have often revealed the real vulnerability of beaches and lead to changes that may escape works based solely on cartographic, photographic, or imagery documents. This is what happened, for example, when many rooms of the Miramar hotel were severely damaged, and the beach in front of them eroded (Fig. 12.13). But the coup de grace came with the storm of March 2012 (Oueslati 2016). The damage was numerous, especially in the western part of the bay. In the aftermath of this storm, the landscape was desolate: many felled palm trees, almost all of the constructions overlooking the beach were damaged and sometimes heavily scoured or demolished (Fig. 12.16), and the profile of the beach has been significantly lowered. At different points, the waves truncated the *tabias* and the ground on which they were built. Many sections show then a superposition of materials of different natures and origins spread over the local sand. Where the waves have advanced inside the hotel enclosures, they often unearthed a superposition of materials reminiscent of that mentioned in the case of the Ain Mariem hotel in

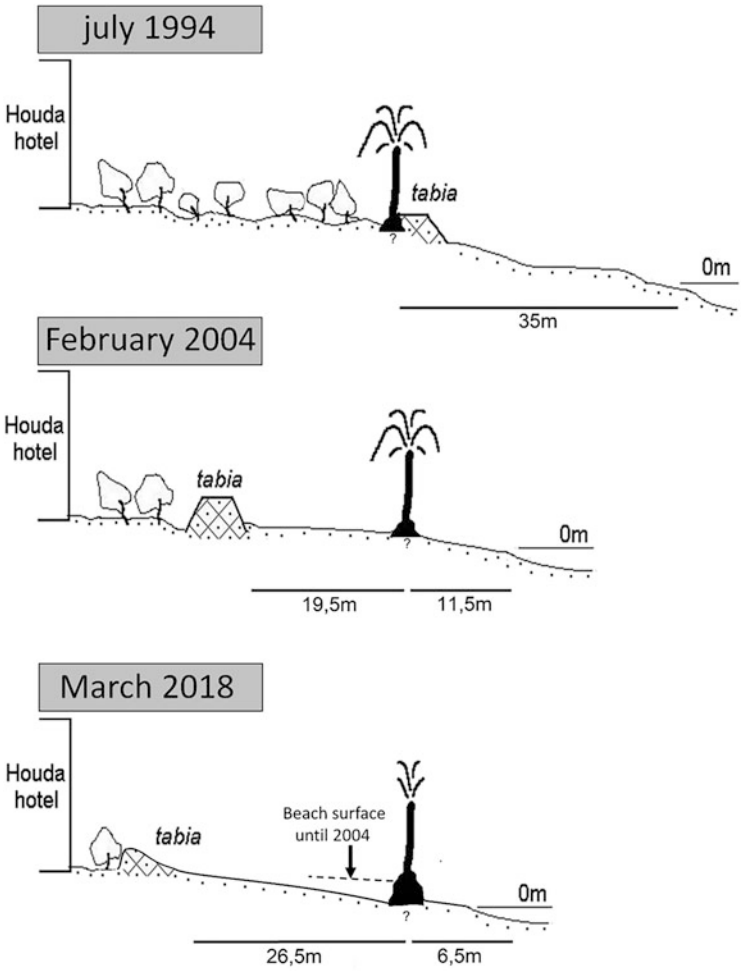

Fig. 12.14 The evolution of the beach of the Houda hotel, between modifications by human intervention and progression of the effects of marine erosion (the palm tree is the same in the different stages)

Bizerte. Here too, the dune sand has been undoubtedly used in construction sites and replaced by imported soil and sometimes by landfill products.

Thus, in addition to their interest in studying the risk of marine erosion, the sites of La Bizerte' Corniche and Skanès provide data that cannot be revealed by works based only on cartographic, photographic, or imagery documents, such as some important characteristics of the managed area nature or the vertical lowering of the beach and its artificial widening. They also illustrate the possibility of abrupt change in the evolution of beaches that were believed to be unaffected by the risk of marine erosion. In addition, they clearly show that the risk of erosion does not always start

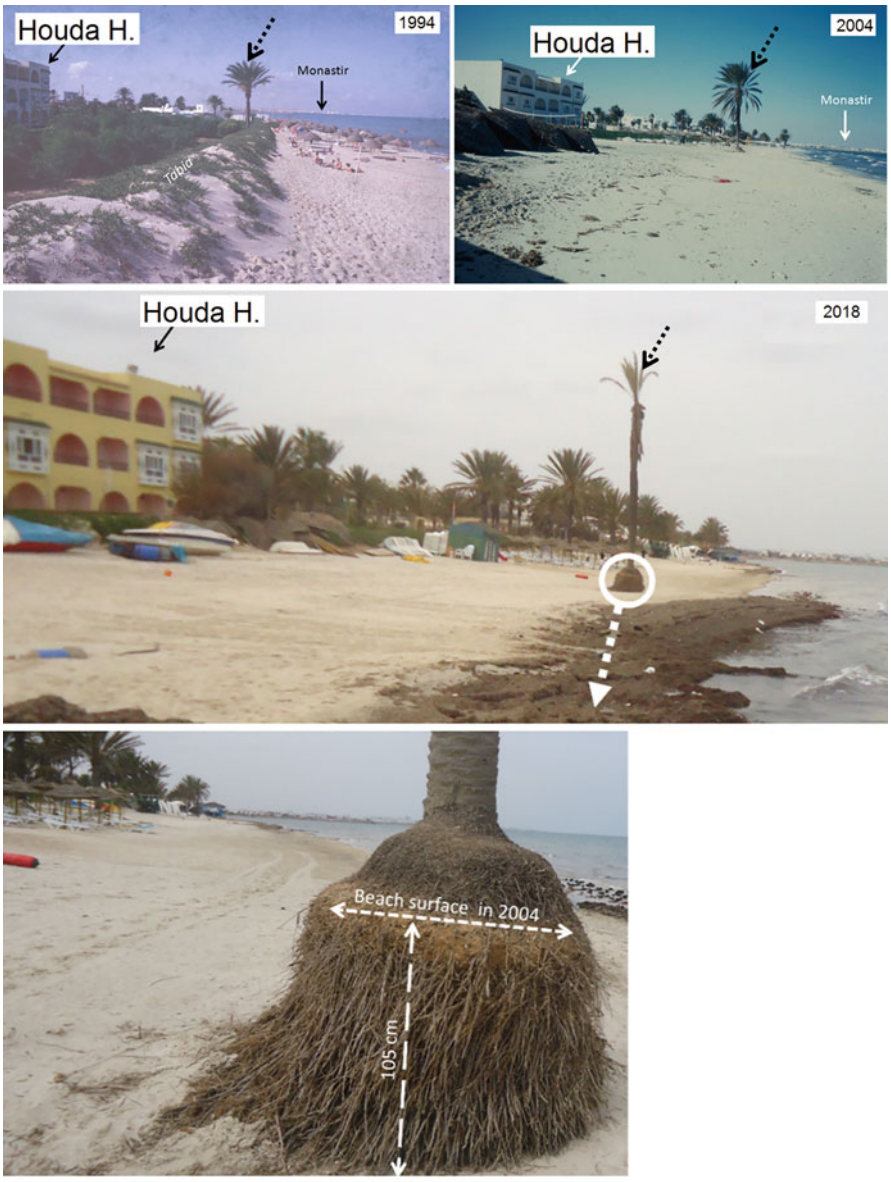

Fig. 12.15 Photos showing the same situations represented in the previous figure. The last photo shows, through the lower part of the same palm tree (indicated by a black dashed arrow), the importance of the vertical lowering of the beach (photos, Ameur Oueslati)

immediately after management that is not suited to the equilibrium of the beach. The problems can be postponed until a moment of disruption of balance. The latter can be natural, such as during heavy storms. It can also be part of the evolution of

Fig. 12.16 One of the illustrations of the state of the beaches of Skanès coast in the aftermath of the storm in March 2012. 19 m is the width of the space that was part of the hotel enclosure before the storm. It corresponds to the distance which separated the felled palm tree (small dashed white arrow) from the sea. We also recognize the debris and the external limit (dark arrows) of a pool which was originally implanted at the expense of the inner part of the beach (photos, Ameur Oueslati, March 2012)

neighboring coastal segments which reflect the dynamic complementarily between the different parts of a given coastline. However, the acquisition of all of this data is important, even essential, for the assessment of the risk and the capacity of the beach to withstand the various hazards, especially in a conjuncture marked, as noted above, by an already favorable natural tendency to marine erosion and a conjuncture of a sea-level rise.

12.6 A Negative Assessment at Different Levels: Beaches Often Unarmed to Face the Challenges of the Future

The results of the evolution undergone by beaches for almost a century and a quarter are negative in large part of the Tunisian coasts. This first appears through the current state of these beaches. It also appears through the evolution of management

practices, decision-makers' attitude, and the delay in new approaches in managing the risk of marine erosion. The situation is likely to become more complicated if we consider the ability to cope with the environmental changes announced for the future (Church et al. 2010). Several beaches are left weakened in the face of the challenges that the sea-level rise will impose.

12.6.1 With Regard to the General State of the Beaches

At the end of the evolution that has taken place since the beginning of the twentieth century, many beaches were severely weakened; others disappeared or lost most of their natural material (Fig. 12.17). This happened, in part, because of flaws in taking into account the interactions of beaches with the land that borders them (*via* coastal currents) or which surround them (*via* rivers). However, the most critical situations characterize the beaches of urban and tourist areas, mainly in the country's north eastern and eastern parts. Building on the seafront without properly considering the requirements of the sediment dynamic within the beach and its complementarity with the foredune was the most fatal error. In addition to the accentuation of marine erosion, this has often resulted in ugly landscapes and sometimes in a degradation of the quality of beaches' material.

Hard protection structures that have increased since the 1980s are now one of the most striking landscape features in many coastal segments. They have, in many cases, accentuated the ugliness of landscapes, and some of them have aggravated the erosion problems. This is particularly the case with groins which have, like port jetties, disrupted coastal transit. The same type of disturbance was caused by the tombolos formed in the shelter of the breakwaters. As we will see later, the trend today is to remove this kind of structures from different sites.

According to the observations we were able to carry out directly in the field until 2015 and their partial update from aerial photographs and Google Earth images, some 240 of the 550 kilometers of beaches in Tunisia are already concerned by the risk of marine erosion. About 20% of them have already lost all their original natural sand and have been the subject of numerous works of protection, most often by heavy structures. These are mainly beaches on the most highly urbanized coasts or tourist areas. Another third of the same 240 km is made up of beaches which already show different forms of weakness and have already been the subject of protection works, especially by private initiatives. Interventions by heavy defense works carried out by the state exist but they still located. However, given the rate of change due to erosion, larger protective interventions should not be long in coming, because the manifestations of the shore retreat are already recognizable even where the managements are very recent and have not yet taken over the entire shore. Considering the coastal segments that have just been the subject of managements and given the ongoing evolution of the occupation of the coasts, we should expect the list of risky beaches to continue to grow. The situation will only get worse as long as the recklessness and imprudences evoked above continue to recur. No less significant

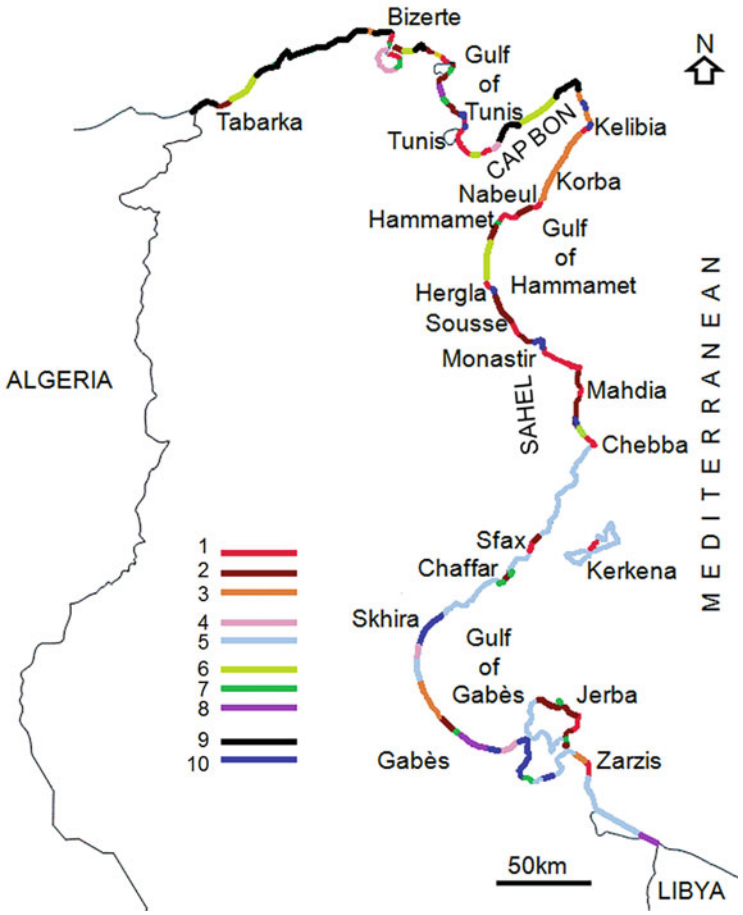

Fig. 12.17 The present state of Tunisia's beaches. 1. Beaches in strong erosion with sometimes, especially in highly urbanized coasts, total disappearance of the original material; various hard protection structures. 2. Beaches already heavily developed; many forms of erosion; protective structures in the most affected sites. 3. Beaches under management; appearance of forms of erosion as managements increase; localized protection interventions, often by private initials. 4. Beaches being eroded in the absence of human intervention. 5. Thin beaches along soft or rocky low coasts; rapidly eroding in loose coasts. 6. Long beaches still largely sheltered from managements; however, forms of weakness are sometimes declared as soon as human intervention has taken place. 7. Beaches in progradation. 8. Beaches in temporary progradation. 9. Coasts with cliffs and rocky coasts, beaches enclosed in creeks and small bays where they escape erosion mainly where there are wadis. 10. Small cliffs with sometimes ephemeral beaches at the foot

also is the fact that erosion is observed, as demonstrated above, in many shorelines containing non-managed beaches.

As for the beaches still relatively sheltered from the risk of marine erosion or which do not show signs of evident modifications, they mainly belong to the north coast, especially to the West of Bizerte and on the West side of the Cap Bon

peninsula. Most of them continue to benefit from significant sediment inputs due, as mentioned above, to their location around the mouths of wadis, in small bays, or in contact with cliffs and rocky coasts in a sandstone geological framework.

The beaches in clear progradation concern a coastal linear of about thirty kilometers in length. They are found around the mouths of some wadis and in the distal part of spits such as that of Rass Rmal in Jerba or those of Bou Rmada and Nakta at the mouth of Oued Chaffar south to Sfax. They are also found at the jetties of some ports and in shores that benefit from a supply from the open sea. The last situation started to take on particular importance in the last two decades, mainly in the southern areas. The barrier islands of Dhar Ghannouche, which appeared recently between Jerba Island and Zarzis, are one of the most telling illustrations (Oueslati 2005; Masmoudi 2010; Akacha 2021). Other examples exist between the city of Gabès and the port of Zarrat; they can be noted on different Google Maps. It was interpreted as the counterpart of destabilization of the sediments consequent to the degradation of seagrass beds (Oueslati 2016) and seems hence to constitute a temporary situation.

Among the various situations identified, it is in the most heavily managed beaches and already affected by the risk that the effects of the sea-level rise will be most felt. More and more, varied and costly protection works are to be expected. The situations will be further aggravated in the lower coasts devoid of dune fields and important wadis, so much so that on the whole it is in the gulf of Tunis and on the eastern side of the country that the beaches will suffer the most.

12.6.2 With Regard to the Evolution of the Occupation of the Coast and the Attitude of Officials and Decision-Makers

12.6.2.1 About Coast Occupation's Evolution and Decision-Makers' Attitude

The interventions and practices that triggered or worsened the erosion of beaches in Tunisia were initially done out of ignorance; the coastline was still very poorly managed, and no major diagnostic studies were available about the risk of marine erosion. But later, they took place in the framework of a certain stubbornness to ignore specialists' advice and not trying to learn from past experiences. Several practices condemned as early as the 1980s and 1990s and sometimes even since the 1970s continued to be reproduced until the very last years.

This is particularly the case for hard constructions on the beach and its dune. Moreover, until the last few years, we continued to encounter recent hard construction in clearly eroding coasts (Fig. 12.18). In some areas the occupation of the foredune continues to take place in the vicinity of buildings that have lost their beaches, that are in the process of erosion, or that have been the subject of significant protection works. Examples are numerous in big cities (Bizerte, Raf Raf, Tunis,

Fig. 12.18 One of the many illustrations of perseverance in reproducing the same mistakes in the Kerkena archipelago. Appearance of hard constructions in a clearly eroding coast. The arrows indicate the same low wall, originally (in 1993) created as a protective structure (photos, Ameur Oueslati)

Kelibia, Nabeul, Sousse, Mahdia, Sfax, Gabès, etc.), but also in areas that still keep a rural character (the coast of Beni Ata near Rass Jebel, the coast between Melloulèche and Sfax, the coast of Kerkena archipelago, etc.).

As for decision-makers and departments in charge of regional planning, we can first mention the lack of firmness in the application of the regulations in force. The law on the delimitation of the Public Maritime Domain (DPM) dates from the 1990s. However, we even continue to find very recent boundary markers very close to the sea, sometimes on the beach or in the intertidal area. This is all the more surprising as it applies even to land still sheltered from shore managements (Fig. 12.19). Moreover, since the promulgation of such law, large coast segments have seen a multiplication of hard constructions on the seafront, frequently on foredunes and sometimes on the internal part of the beaches. Demolitions have certainly taken place, but they have often remained limited to of the structures encroaching on the beach and the foredune. This is what we saw, for example, during interventions in some hotels of Sousse during the months of March and April 2022. In any case, the number of managements affected by such a measure remains insignificant compared to all those in an illegal situation. Moreover, encroachment on the beach and the DPM has even continued within the framework of large approved housing estates. The situation in the southern part of the city of Gabès provides one of the most glaring illustrations of the disconnect between the legal texts and their application. A large housing estate (Bou Chemmaoui on the advertising panel displayed until November 2017 at the entrance to the site) was built on the foredune and the internal part of the beach, in a particularly vulnerable coast (Fig. 12.20). This is indicated by vestiges of military structures (a blockhaus and a machine gun nest) inherited from the Second World War period and are now part of the intertidal zone. The state of waterfront dwellings also shows it in the neighboring coastal segments both on the Northside and on the Southside. Some of these dwellings are already subject to severe erosion while they are sometimes very recent.

Fig. 12.19 A very recent boundary marker of the Public Maritime Domain located in the intertidal zone (photo, Ameur Oueslati, Nov., 2017). It is already beginning to be dislodged by waves and is overtaken by seawater during storms, as the puddles visible on the track suggest. According to the DPM definition, it must be further inland!

Fig. 12.20 The northern end of the Bou Chemmaoui estate created at the expense of the dunes bordering the beach in a coast in clear erosion (Photos, Ameur Oueslati, Nov. 2021): 1. the northeastern part of the estate; 2. the foredune; 3a. blockhaus; 3b. machine gun nest; 4. recent dwellings but already exposed to the problem of marine erosion

12.6.2.2 Delay in Soft Protection Methods' Adoption and Prospective Approaches

One of the most serious inconsistencies in the fight against marine erosion lies in the persistence in the use of methods which have revealed their limits and which have sometimes been criticized (Paskof and Clus-Aubry 2007). What happened, for example, in the beach of Sidi Ejjehmi-Soliman in the bay of Tunis gives one of

the most expressive illustrations. To protect this beach as well as the village of secondary residence of Soliman Beach and the Solymar hotel, the choice was made on the technique of breakwaters. These allowed the appearance of tombolos, but has at the same time caused a degradation in the quality of the environment as well as a segmentation of the beach and deprived certain sectors from the littoral drift inputs. Immediately to the west of the precited village and hotel, the shore has receded at an average speed sometimes greater than 7 m/year (Marzougui and Oueslati 2017). The heaviest damage was recorded immediately west of the Hotel Solymar. The shore retreat resulted in the disappearance of a row of the lots and the outer street of an estate still in progress. In order to remedy the catastrophic situation, new measures were undertaken since 2018. They must lead to the removal of most breakwaters and to resort to a combination of different techniques: groins, riprap dikes, artificial replenishment, and reconstruction of the foredune. The works now complete, the site has changed in appearance. The wide sandy shore which attracted the housing estate of Sidi Ejjehmi, for example, has given way to a thick riprap dike (Figs. 12.21 and 12.22). All this happened while a few kilometers to the West, in Hammam Lif, breakwaters created in the mid-1980s caused great damage, mainly for the quality of the environment following the eutrophication of the water and the regular accumulation of large quantities of seagrass in the cells that separate the tombolos. This has even sparked many protests by the inhabitants. The disadvantages of the use of breakwaters were, in addition, revealed in other beaches like in Sousse and Mahdia and more recently in Jerba (Oueslati 2004).

The risk of marine erosion has been, in addition to the aforementioned recklessness, complicated by a great delay in the use of soft protection methods and a lack in the recourse to managements that do not lead to important disturbances in the beach sediment dynamics. We think mainly to light constructions and soft protection solutions recommended for several years by numerous studies (Paskoff

Fig. 12.21 The culmination of the evolution in a part of the coast of Sidi Ejjehmi-Soliman over the past 12 years: the beach that attracted the housing estate was sacrificed. The same fate was reserved for the dunes which relayed it on the internal side (photos, Ameur Oueslati)

Fig. 12.22 The culmination of the evolution in a part of the coast of Sidi Ejjehmi-Soliman over the past 12 years: the beach that attracted the housing estate was sacrificed. The same fate was reserved for the dunes which relayed it on the internal side (photos, Ameur Oueslati)

1993; Paskof and Clus-Aubry 2007; Fema 2011). However, the country has undeniable patrimony in this area, unfortunately abandoned and sometimes forgotten. Archival documents from coastal municipalities as well as numerous postcards that circulated during the first half of the twentieth century bear witness to this. Photos taken in Bizerte show the alignments of small wooden rooms on the beach that served as showers or shelters for summer visitors. At Sidi Erraies, in the eastern part of the bay of Tunis, the beach was, until the 1980s, bordered by light constructions on stilts. Likewise, the use of wood groins was common in the beaches of the suburbs of Tunis, particularly in Rades and between La Goulette and Carthage-Kheireddine (Fig. 12.3). The remains of such groins were yet recognizable in the field until the 1990s. However, the most important light constructions are the famous rotundas which were one of the most characteristic features of the landscape of the shores of the northern suburbs of Tunis. Made of wood, they are set in the water and connected to the beach by suspended walkways (Fig. 12.23). Nowadays, we note a certain return to some past practices. This still however limited. Rare constructions reminiscent of rotundas are used here and there, as in the Bay of Skanès or Jerba-Zarzis.

On the other hand, the strategic retreat principle is almost absent. If some hoteliers have agreed to cede land, it is because part of the buildings was severely damaged by the waves and became unprofitable. This was the case in the tourist area of Skanès following the storm of March 2012 (Fig. 12.24). Previously, the owner of the Jazira hotel, the oldest in the tourist area of Jerba, was forced to destroy the rooms closest to the sea.

The delay was also obvious with regard to the artificial replenishment of beaches. However, this method has been mentioned and retained as one of the solutions in many studies. These were carried out at the request of the departments responsible for the management and development of the Tunisian coasts. Some of them date

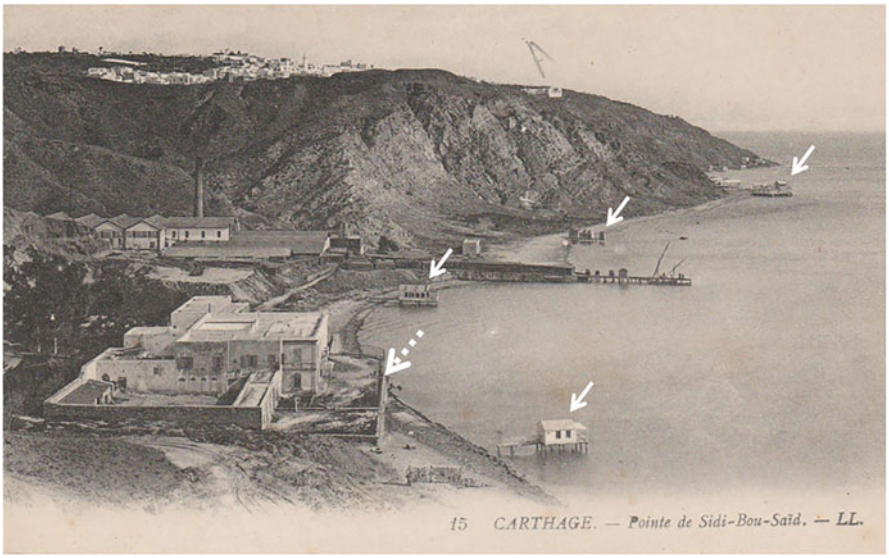

Fig. 12.23 One of many postcards from the first half of the twentieth century showing the rotundas (continuous arrows); here the situation of the northern suburbs of Tunis between Amilcar and Sidi Bou Said. The state of the waterfront construction attests to the age of the risk of marine erosion (dashed arrow) (the original photo is owned by the author)

Fig. 12.24 Willful destruction of buildings encroaching on the beach. Example in Skanès the day after the storm of March 2012 (photo, Ameur Oueslati, 2012)

back to the 1990s. Occasional attempts have been made here and there, most often by private initiatives and without prior study or follow-up. It is only in the last 5 years that significant interventions have taken place. The most important were

Fig. 12.25 Raf Raf beach, one of the rare beaches to have benefited from important artificial replenishment (the coast of Ejjehmi-Soliman in the Gulf of Tunis offers another significant example). This followed attempts at protection by hard structures. The photos also show the evolution of the situation since 1993. We recognize the same building (unfinished on the first two photos) that serves as a landmark. The rapid erosion is mainly due to the waterfront constructions all built on the foredune (photos, Ameur Oueslati)

undertaken in the beach of Raf Raf (Fig. 12.25) and in the beach of the coast extending between Sidi Ejjehmi and Soliman. In this second case, works were carried out, as mentioned above, parallelly to a breakwater removal. The beaches concerned have been greatly extended. A follow-up through observations and repeated measures will help to better understand their reactions to these new interventions.

Finally, the only sensitive effort in soft protection was devoted to the regeneration of the foredune by the ganivelles method. This has been applied at several sites and has often given encouraging results. The first experience was carried out on Mahdia beach in the 1990s. But requiring a minimum of space, this technique is impossible in the beaches which need it the most because they have become very narrow and their foredune lies under the concrete.

12.7 Conclusion: Tunisia's Sandy Beaches Leave Weak in the Fight Against the Predicted Sea-Level Rise

This work considered the current state of the beaches along the Tunisian coasts as well as the trend which marked their evolution over a significant period, about a century and a quarter long. This is important for the definition of the aptitudes of these forms for management. It is also essential for the assessment of the risk of marine erosion and prospective approaches required by the announced environmental changes.

It appears that, despite an unfavorable natural context for important marine erosion, Tunisia's sandy beaches have lost an essential part of their substance since the beginning of the twentieth century. Some of them have been totally eroded. The evolution has often been measured in the framework of works based on exploiting topographic maps, aerial photographs, and satellite images. This allowed significant results, but these do not reflect the whole reality and are sometimes even misleading, because monitoring the situation by repeated observation in the field has shown that the countenance of the beach can change suddenly following exceptional natural events or following some specific human intervention. This can be of great importance for knowing the true condition of the beach and should help better predict its future evolution. Either way, the risk is greatest in the beaches cut off from their upstream and coastal transit or belonging to the coasts subject to the most numerous and dense waterfront managements. These are often both a cause and a victim. Several of them, including protection structures, are part of reckless practices that unfortunately have continued to be reproduced while their misdeeds have been known for several decades.

The problems have also been accentuated by the lack of law enforcement and the delay in resorting to new beach management and protection methods. Only the technique of reconstituting the foredune has received some attention. But it is often impossible on the shores that need it the most because the natural beach has become too narrow and bordered by hard constructions. However, the country has an undeniable heritage in this area.

A glimmer of hope seems to be announced with the adoption of the technique of artificial beach nourishment, which has just been applied to two quite extensive beach portions at Raf Raf and in Ejjehmi-Soliman coast.

Despite everything, the general assessment remains negative. The damage, already heavy, may worsen when the newly managed beaches are added to the list of those which have reached the risk level. Indeed, the declaration of the last and the manifestation of its damage take some time. More and more beaches will call for protection or restoration interventions. In addition, the situation can only worsen further with the predicted sea-level rise. On the whole, the most worrying situations will be observed in beaches that do not benefit from significant sediment support and are bordered by continuous concrete and masonry buildings. In addition to the accentuation of the waves' energy by their reflection, the last situation will not allow solutions to adapt the beaches to the new conjuncture. One of these solutions is landward migration.

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