WORLD BANK GROUP

N° 04 - May 2021

Maghreb Technical Notes Series

Disappearing coasts in the Maghreb: Coastal erosion and its costs.

Martin Philipp Heger and Lukas Vashold

Acknowledgments

This report is the product of an extensive collaboration between the World Bank, the National Oceanographic Center (NOC) of the United Kingdom and the European Space Agency. The numerous and rich discussions and exchange of information has been critical for the preparation of this report.

The report was written by Martin Heger (Senior Environmental Economist) and Lukas Vashold (Research Consultant), together with Stephen Carpenter (from NOC) and Miguel Toquica (Disaster Risk Management Consultant). The drafting team would like to first and foremost acknowledge the invaluable contributions from Cristine Sams at the National Oceanographic Center of the United Kingdom. The support of Christoph Aubrecht (European Space Agency) is also greatly appreciated. The team is most grateful for overall guidance on this report to Lia Sieghart (Practice Manager, Environment, Natural Resources and Blue Economy Global Practice MENA Region). In addition, very useful comments were received from Marcelo Acerbi (Senior Environmental Specialist), and Marjory-Anne Bromhead (Consultant).

The team would like to acknowledge the financial support of this study through the Korean Green Growth Trust Fund (KGGTF).

Disappearing coasts in the Maghreb: Coastal erosion and its costs

Executive Summary

Coastal areas are important ecosystems and at the same time buzzing centers for large parts of the population and economic activity.

Globally, coasts are home to around 40% of the population and all around the world major cities are located on the coast. In the Maghreb, the share of total population living in the vicinity of the coast is even higher ranging from 65% in Morocco to 85% in Tunisia, with the livelihood of their inhabitants often depending on intact coasts and beaches, for example in the tourism sector. Moreover, much of the individual countries' industry is located at the coast and coastal infrastructure such as ports plays a crucial role in the exports of goods.

Coastal erosion is a relentless process, one that is only to exacerbate with climate change.

In the past three decades, the Maghreb was the second most coastally eroding region, following only South Asia in a global comparison. The average annual coastal erosion rate of 0.07 centimeters, is surpassed significantly especially in Tunisia, which has average coastal erosion rates of 0.64 centimeters per year, and Morocco, which has rates of 0.14 centimeters on the Mediterranean coast and 0.12 centimeters on the Atlantic coast. These country averages mask substantial heterogeneities, and certain hotspots in these countries are disappearing at faster rates, of several meters per year.

Costs due to inaction with regards to coastal erosion are high, even when only considering lost land and destroyed assets.

Coastal erosion has many negative consequences, and this report focusses on estimating the effects on the destruction of coastal assets (such as land and buildings). For the asset destruction cost quantification, damages to coastal land and near-shore assets (buildings) are monetized using local data on property prices in Algeria, Libya, Morocco and Tunisia. The estimated annual asset destruction cost from coastal erosion amounts to the equivalent of 2.8% of GDP in Tunisia, 0.7% in Libya, 0.4% in Morocco, and 0.2% in Algeria.

There are also economic costs in terms of reduced revenue from sectors such as tourism that depend on the quality of coastal areas.

Coastal erosion also negatively affects the revenues from activities depending on the blue asset. For example, reductions in tourism. International survey evidence from other coastal areas shows that tourists' propensity to return decreases substantially with continued erosion of beaches. The conclusion is that some of the hotspot beaches that have already more than half disappeared may still attract tourists, although the question in the face of continued coastal erosion trends is 'for how much longer.' To properly account for revenue losses and hence indirect costs stemming from coastal erosion further research is called for, especially in coastal areas already under threat of losing their beaches.

To identify coastal erosion hotspots accurately a novel higher-resolution dataset was created.

In cooperation with the National Oceanography Centre of the United Kingdom, original data using high resolution Earth Observation data together with state-of-the-art techniques to gain in accuracy regarding coastal dynamics are created and analyzed. Using 50m resolution segments along the coast instead of ones being 5 to 10 times larger, as is done in recent global evaluations, along with statistical temporal change detection provides new, granular evidence on the evolution of Morocco's and Tunisia's coastline. Using more granular segmentations of the coast than previous studies enables zooming in on these hotspots and studying the site-specific developments and their drivers. The report illustrates the merits of this novel dataset by assessing the changes in the coastal landscape, where large parts are retreating at fast rates. Hotspot examples that were subject to severe erosion in the past decades analyzed from Tunisia in the report include beaches on Djerba, Hammamet, and Soliman.

The precise nature of the dataset can be utilized to study shoreline changes not only retrospectively, but also for predicting future erosion.

Accurately forecasting changes in the shoreline at a policy-relevant timeframe (i.e. the next 10 or 20 years) can prove as immensely valuable to base relevant decisions upon. Furthermore, the rich structure of the analysis employed can be exploited to study the effects that different protective structures had on the parts of the coast they were intended to protect. Similarly, the merits of the novel dataset in these regards are illustrated with case studies.

This report aims to inform decision-makers about the extent and impact of coastal erosion as well as stimulate further research in close cooperation with local authorities and research institutions.

Even though the presented estimated costs of inaction only provide a very conservative lower bound of the economic costs accruing from coastal erosion, they are substantial and should come as a waking call for decision-makers. The detailed investigation proves as a valuable starting point to gain insights in the erosive processes along Maghreb's coasts. To improve current understanding, the report calls for further research efforts in close cooperation with local researchers both from academia and government authorities. One of the proposed research activities includes an impact assessment of coastal erosion also on economic flows, on top of the cost to assets as done in this report. For this, detailed surveys among both tourists and residents are crucial as well as accurate stock-taking of endangered coastal activities. Furthermore, a multitude of further research activities is desirable for better understanding the physical process of coastal erosion at Maghreb's coasts and to better inform such cost assessments. These include extensions of accurate forecasting at large scales but also for specific sites such as the ones presented here for policy-relevant timeframes. To further improve upon them, detailed studies on coastal dynamics such as sediment transport, wave dynamics and geomorphological characteristics would be highly valuable for the formulation of appropriate policies.

A forthcoming regional report by the World Bank, titled "Blue Skies, Blue Seas," provides a detailed discussion on how to combat coastal erosion.

The present report constitutes an important step in recognizing the threat coastal erosion is for coastal assets and activities. Given these challenges it is imperative for policy-makers to formulate suitable policies that address them at specific sites keeping in mind the possible spillover effects that certain protective measures can have. While this technical report focusses rather on the determination of the extent of coastal erosion and quantifying the direct costs of inaction associated with it in the Maghreb, several possible avenues that can be taken to combat coastal erosion are outlined in a forthcoming regional report entitled "Blue Skies, Blue Seas". This other World bank report discusses other pressing environmental issues that the Middle East and Northern Africa (MENA) region faces besides coastal erosion, namely air pollution and plastic marine pollution, and provides recommendations drawing on regional as well as international experience and best practices. This includes detailed information on measures to tackle coastal erosion such as protective measures, targeted regulations and coastal development strategies all under the tenants of a comprehensive Integrated Coastal Zone Management scheme.

Coasts and their economic importance in Maghreb

Coastal areas all around the world are home to a large share of the population.

Coasts host a huge number of different biomes, with these ecosystems hosting an extensive host of different species of the flora and fauna nowhere else to be found. While globally seen large parts of the coastline are still untouched by human presence, ever increasing pressure is put on them by rising alteration of natural characteristics (Martinez et al, 2007). Globally, more than 40% of people live within 100 km of the coast and this number is set to increase further (Maul & Duedall, 2019). Many settlements are concentrated within 5km of the coastline, population densities at the coast are around three times higher than the global average (Small & Nicholls, 2003) and twenty-one of the 33 world's megacities are located on the coast (Martinez et al, 2007).

Globally, these zones are immensely important for economic development and are crucial ecosystems providing habitat for a vast flora and fauna.

Coastal zones are the most important areas for the socio-economic development of coastal countries and their attractiveness has led to a disproportionately rapid expansion of economic activity and tourist resorts along them (Nicholls et al, 2007). They are also important habitats for a huge range of different flora and fauna, fostering and preserving biodiversity (e.g. Gray, 1997) and acting as carbon sinks, for example in the form of mangrove woods (Laffoley & Grimsditch, 2009). The value of ecosystem services provided by these zones has been calculated to amount to more than USD25 trillion per year, with natural ecosystems contributing the most (Martinez et al, 2007).

Maghreb's coastline stretches almost 7,500 km and is even denser populated, with every single capital city located there.

The Maghreb is bordered by the Atlantic Ocean and the Mediterranean Sea. The Mediterranean coasts have been populated for millennia and most of the largest cities are situated at them, while the North Atlantic has Morocco's largest city on its shoreline. In the Maghreb, population concentrations are even higher than global or regional ones and range from 65% in Morocco to 84% in Tunisia (Maul & Duedall, 2019). The capital city of each respective country is located directly at the coast and other major cities and economic centers are clustered all along Maghreb's coastlines (e.g. Tangier in Morocco or Sfax in Tunisia). Increasing urbanization pressures and partly uncontrolled migration to coastal urban centers have exacerbated the share of the population potentially affected by coastal erosion (Ahizoun et al. 2009; Anfuso et al. 2011). Population growth also brings development leading to changes to the natural environments and habitats that provide natural erosion protection such as wetland 'sabkha' (Chekirbane et al., 2013, Amrouni et al., 2019).

Given the concentration of settlements along them, Maghreb coasts are also major hotspots for industries and economic activity.

The concentration of human settlements along the coasts also brings a concentration of economic activity. This phenomenon is especially prevalent in certain countries. For example, in Morocco, where around two thirds of the population lives nearby the coast, more than 90% of industries have their operations at the coastal zone (Aitali et al, 2020) and coastal tourism, largely dependent on intact beaches, is a major contributor to the national economy (Snoussi et al, 2009). Apart from these sites, cultural and natural sites alike are located at the coasts, threatened by coastal erosion processes (Trakadas, 2020). Similarly, in Tunisia more than 83% of industrial firms are located in specialized industrial zones along the coast of Sahel, a region approximately stretching from Bizerte to Sfax[1], and 90% of the country's total economic output is achieved in near-shore areas.[2] In Algeria, more than 60% of the national industry is localized in or near coastal cities (Guenduozi, 2017). Furthermore, the economies of both Algeria and Libya depend heavily on the petroleum sector, making up 96% of total goods exports in Algeria and more than 40% in Libya (Camporeale et al, 2021). Ports and coastal cities are important trans-shipment centers for these goods and regional transportation hubs such as ports and other economic centers are located in low-laying coastal areas all around MENA (Schäfer, 2013), where sea level rise and coastal erosion poses major threats to them.

Parts of the Maghreb's population are dependent on marine resources that are threatened by further environmental degradation.

The fishing industry is of economically significance in some Maghreb countries, especially in Morocco. Moroccan fisheries and industries connected to them contribute around 2.3% to national GDP and create employment for almost 700,000 people (directly and indirectly) in 2014. Furthermore, around three million people depend on fisheries for their livelihoods.[3] Similarly fishing plays an important role in the Libyan economy, constituting on of the largest sectors after the oil and gas industry (Maltig et al, 2018). Moreover, the large coastal areas are imortant to the livelihoods of hundreds of thousands of people in the Maghreb and MENA more broadly, with many of them vulnerable and poor, which often rely on small-scale fisheries and aquaculture that have been increasing substantially in recent years (Sieghart et al, 2019; OECD-FAO, 2018).

For several countries in the Maghreb, intact beaches and coastal zones are vital for their attractiveness to tourists.

Maghreb countries such as Tunisia and Morocco rely heavily on their beaches and associated recreational services in order to attract international as well as domestic tourists. For example, Djerba island at the Southern end of the Tunisian shoreline accounts for around a quarter of all international tourists arriving in Tunisia (Carboni et al., 2014) and tourism there is focussed strongly on its coastal assets to attract tourists (Widz and Brzezinska-Wojcik, 2020). In Morocco, the Tetouan coast is based mainly on beach tourism that is threatened by the fact that 70% of its beaches, including the most popular and visited ones, undergo accelerated erosion (Flayou et al, 2018). Tourism may have exacerbated these effects by contributing to advancing rates of artificialization of the coastline, in the course of which over 95% of the coastal dunes have been degraded (El Mrini, 2011). Losing the natural assets represented by beaches can have severe adverse effects on the tourism sector by diminishing the number of tourists or threatening tourism-related infrastructure.

[1] *https://oxfordbusinessgroup.com/overview/forging-ahead-uneven-growth-industry-subsectors-remains-challenge*
[2] *https://www.kfw.de/stories/environment/climate-change/coastal-protection-tunisia/*
[3] *http://www.fao.org/blogs/blue-growth-blog/morocco-a-maritime-fishing-nation-works-to-develop-its-aquaculture-sector/en/*

The first part of this report analyzes the direct human and economic effect of inaction to coastal erosion in the Maghreb.

An assessment of the direct costs that arise from inaction with regard to coastal erosion to land and built assets for Algeria, Morocco, Tunisia and Libya is conducted. It reveals that even though these estimates include only a part of the overall costs arising due to a degradation of the coastline of these countries, the economic impact of coastal erosion is substantial. Notably, the costs assessed only cover direct costs due to coastal erosion, in the sense of lost land and destruction of built assets, not including such costs that arise from lost productive activity and economic flows. To fill this gap, the report stresses the need for further research in this area to enhance understanding of coastal erosion and its costs for coastal communities.

The second part draws on a novel dataset to assess the coasts of Morocco and Tunisia in more detail, identifying hotspots of coastal erosion, forecasting shoreline changes and evaluating the impact of different protective measures.

This part documents some of the proceedings of an ongoing cooperation with the National Oceanography Centre of the United Kingdom and the European Space Agency. It analyzes the specific local erosion dynamics in Morocco and Tunisia in more detail by employing high-resolution satellite images and sophisticated procedures that properly account for phenomena such as the breaking of waves as they approach the shore to avoid misclassification issues. This makes the identification of local hotspots of coastal erosion at a very detailed scale possible. Additionally, models are employed to forecast future changes to the shoreline and retrospective evaluation of the effects of different human interventions in the coastal landscape is exemplified.

Erosion of the Maghreb's coasts and its economic costs

This section provides an overview of historical changes of the Maghreb's coasts before turning to the costs associated with this erosion. The direct economic costs of coastal erosion are estimated in the next subsection for four selected countries. The final subsection discusses the implications of coastal erosion for tourism revenue.

Historical changes of coasts in the Maghreb

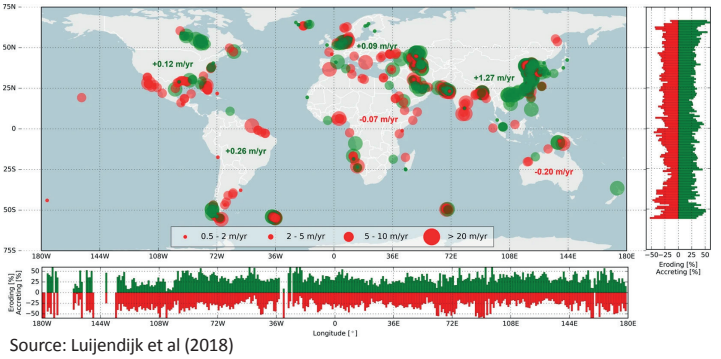
"If no measures to combat erosion are undertaken, sandy beaches will inevitably be lost, with cascading effects on the economy and the wellbeing of the local populations, particularly those dependent on tourism." (Snoussi et al discussing coastal erosion in Morocco, 2017)

Changes in coastlines and the gradual disappearance of beaches are processes that take place all over the world, however with regional variation.

Changes in coastal shorelines are a pervasive process, taking place in almost any part of the world with access to the seas. However, the specific dynamics of these processes play out quite differently across regions and countries. Shorelines and beaches can accrete (gain area), erode (loose area) or stay stable over time. In a global analysis, satellite images for equally-sized segments (so-called transects) along the shoreline were analyzed and average changes of sandy coastlines were calculated for the period from 1984 to 2016 (Luijendijk et al, 2018). In Figure 1 below, red dots denote erosion hotspots and green ones those where accretion is prevalent, with the size of the dots indicating the severity of these processes. Globally, Asia has seen some of the most severe changes in coastal changes, both in the form of accretion (mainly in East Asia) and erosion (mainly in South Asia). Regionally aggregated, it can be found that for Africa and Australia are the continents where beaches show net erosion over the period of investigation (Luijendijk et al, 2018), whereas other studies find that erosion of coasts is prevalent for each continent and ocean (Mentaschi et al, 2018). The Southern Mediterranean coast, particularly in the Maghreb, is characterized by more severe erosion.

Figure 1: Constantly changing coastlines

Eroding and accreting beaches



Source: Luijendijk et al (2018)

The sources of coastal erosion are manifold and depend on shoreline characteristics as well as their utilization.

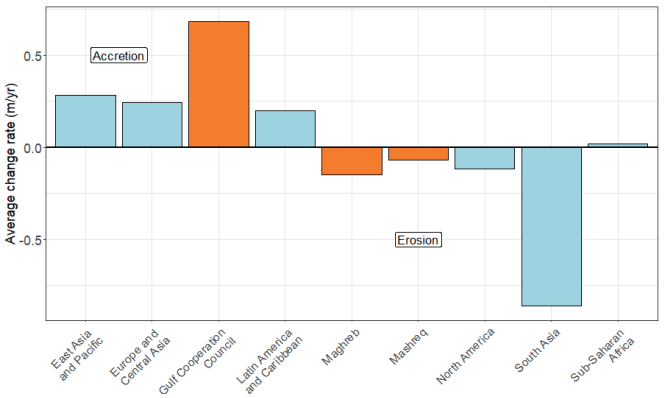
There are a number of factors that drive coastline change which are often split into human-induced factors (coastal subsidence, coastal protections, tourism infrastructure or land reclamation) and natural physical forcing elements (e.g. storm events, sea-level rise, sediment transport) (Sytnik et al., 2018). Coastal areas with different tidal dynamics and wave energy incidences demonstrate unique coastal morphologies (Hayes & FitzGerald, 2013). Fluvial and alongshore sediment transports are major morphodynamical processes which determine the shape of the coastline (Sytnik et al., 2018) and often determine how the coast is divided into management cells when implementing a holistic management scheme. Human interventions, such as ports or groins, intervene in the hydrodynamic processes along the shoreline. Often, they stabilize areas by sediment build up in one location but starve the sediment and intensify the erosion rate at other locations. Globally, anthropogenic factors are found to be dominant drivers of change, with natural disasters such as extreme storms or tsunamis being important. Rising sea levels and more frequent extreme events due to climatic changes are considered to enhance trends in coastal erosion in the future (Mentaschi et al, 2018).

In a global comparison, the Maghreb's coasts are the world's second fastest receding, falling short of South Asia only.

Computing average net erosion rates for MENA's sub-regions shows that the Maghreb and the Mashreq region have seen their beaches and coasts erode in the past decades, while GCC's coasts have accreted substantially. As can be seen in Figure 2 below, comparing these average erosion rates to regions worldwide reveals that the net erosion of Maghreb's coasts is only topped by the massive erosion rates of South Asia's shorelines. In the Maghreb, beaches were retreating by an average of 15cm per year in the period 1984-2016. Comparing the Maghreb's net erosion rate with ones recorded by Northern and Eastern Mediterranean countries, it is revealed that Maghreb exhibits the fastest receding shores at the Mediterranean basin. Similarly, other parts of the African coast are eroding at a slower pace, albeit the consequences have been severe in some countries (see Croitoru et al, 2019).

Figure 2: The Maghreb is the second fastest coastally eroding region

Net coastal erosion by region, average rate from 1984 to 2016



Source: Authors based on Luijendijk et al, 2018

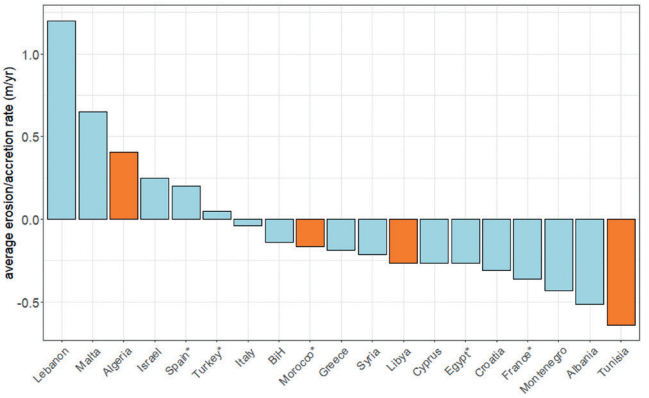
Note: The Maghreb region comprises Algeria, Libya, Malta, Morocco and Tunisia. The Mashreq region includes Djibouti, Egypt, Iraq, Iran, Jordan, Lebanon, Syria, West Bank and Gaza as well as Yemen. The GCC refers to the high income Gulf countries of the Mashreq region, namely Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates.

At the Mediterranean basin, Maghreb countries have seen severe erosion rates, with Tunisia exhibiting the highest rates of all countries.

The regional comparison presented above masks some heterogeneities with respect to retreating shorelines. For example, within the Maghreb region, Tunisia, Libya and Morocco face net erosion of their beaches, while in Algeria accretion dominates, as can be seen in Figure 3. North African countries are especially at risk to coastal erosion as they lie within the transitional zone between subtropical temperate and continental climates that are exposed to forecasted climate change effects (Amrouni et al., 2019). The average sandy beach shoreline retreats 12cm per year on the Atlantic coast of Morocco, 14 cm on the Mediterranean coast of Morocco, and 64cm on the coast of Tunisia, the highest rates of retreat all along the Mediterranean basin. It has been found also elsewhere that Moroccan coastlines are migrating landward and beaches are shrinking (see Snoussi et al, 2017). Similarly, Libyan coasts have seen distinct net erosion retreating around 27cm per year. While Algerian and Maltese coasts showed overall accretion, locally, parts of their beaches have shown relatively high erosion rates as well.

Figure 3: Tunisia's coasts are the ones receding the fastest at the Mediterranean basin

Net coastal erosion by country; average rate from 1984 to 2016



Source: Authors based on Luijendijk et al, 2018

Note: For countries with an asterisk, erosion rates were calculated for the coasts along the Mediterranean basin only. Data for Slovenia and Monaco missing.

Getting an overview of coastal erosion at a national scale while also being able to determine the situation at specific hotspots requires comprehensive yet granular analyses of countries' coastlines.

To gain an understanding of the state of a country's coast comprehensively studying the coastline on a large scale is important. However, coastal erosion dynamics can vary even at very specific sites, with some parts of a beach eroding while others accrete. Hence, once certain erosion hotspots are identified, deriving detailed insights in the specific dynamics and drivers of changes in the coastal landscape hinge on the granularity of observations, both on a spatial and temporal scale. This necessary combination motivated the analysis carried out in cooperation with the National Oceanography Centre of the United Kingdom that will be laid out in more detail in Section 3. The very granular yet comprehensive analysis involving high-resolution satellite images allows for the assessment of the state of coasts on a large (e.g. national) scale to identify specific erosion hotspots, while simultaneously enabling in-depth study of site-specific dynamics and their possible drivers.

Translating the physical process of coastal erosion into economic terms concerns both costs stemming from destroyed assets and costs in the sense of foregone economic activity.

Coastal land and physical assets such as buildings often derive large parts of their value from the proximity to the coast but are also exposed to the detrimental effects of shore retreatment. The next section assesses the direct costs that arise from inaction to coastal erosion in terms of lost land and destroyed assets for the Maghreb, in particular for the Northern African countries Algeria, Libya, Morocco and Tunisia. Losses of physical assets and foregone revenues from economic activity based on them are closely intertwined, especially for activities that are based on coastal proximity such as beach tourism. While the following analysis does not explicitly account for these losses in revenues and economic activity, also due to lack of reliable information, the final subsection of this section explores how coastal erosion is affecting them drawing on international experience, with a focus on possible effects on tourism.

The cost of coastal erosion due to the destruction of land and built assets

Given that the coasts in some Maghreb countries have already eroded severely, one does not have to wait for Sea Level Rise to continue to create challenges to coastal communities.

Coastal erosion is already happening, has been happening for at least some decades now, and is threatening coastal communities, livelihoods, and ecosystems. Here, the threat that coastal erosion poses to homes and livelihoods is assessed, the human exposure to coastal erosion is analyzed and an estimate of the economics of coastal erosion for the countries in the Maghreb is established. It should be stressed that the total costs of coastal erosion are most likely larger than the conservative estimates provided here, given that we only quantify the direct costs of inaction here.

Total costs arising from eroding coasts importantly include costs from lost revenue generation, for example in the tourism sector. Lack of reliable data and studies to build on make estimating these costs challenging. Thus, we review some of potential implications of coastal erosion for economic flows, with a focus on those arising from tourism, in the next section and highlight some approaches that could prove useful for conducting such an exercise in the future.

Quantifying the direct costs of inaction due to coastal erosion amounts to estimating the adverse effects to physical assets like buildings as well as the value of land lost.

The average erosion rates are extracted from the global dataset on historical shoreline changes from 1984 to 2016 already mentioned above (Luijendijk et al, 2018).[4] Following previous studies on the quantification of the economic effects of coastal erosion (see e.g. Croitoru et al, 2019), we focus on areas in countries that are subject to land loss.[5] In other words, we do not value the accretion of areas. This is largely because whereas with coastal erosion the economic effects are always negative as territory is lost, with coastal accretion, they can be negative or positive. For example, accretion near a harbor's entrance may hinder ships from entering the port and lead to siltation of pathways, necessitating dredging works to maintain them. Similarly, when rivers are used for the shipment from the ocean to inland destinations, accreted areas can block the entrance of them. Furthermore, even when accreted land is not detrimental by itself, it remains unclear whether it can be used for development or recreational purposes. Conversely, accreted land, as a result from land reclamation projects of coastal development projects, are obviously generating economic value. In Libya, Morocco and Tunisia, more than half of the coastline is subject to coastal erosion, lower shares are reported for Algeria. Tunisia is the country with the highest rate of erosion for eroding sections, which are losing 2.4 meter a year on average, followed by Algeria with 2.1 meter a year erosion, though for a smaller part of the coastline. For Libya and Morocco, the historical erosion rates are lower with around 0.9 meters per year (see Table 1).

Given these erosion rates and information about the length of the eroding coastline, the average amount of eroded area per year is calculated.

This information is provided in the final column of Table 1. These figures serve as a measure of yearly land loss due to coastal erosion in the countries under scrutiny. The amount of area lost due to coastal erosion per year ranges from 90 hectares in Algeria to almost 250 hectares in Tunisia. The subsequent calculations of yearly direct costs arising from shore retreat are based on these values.

Table 1: Eroded coastal area in Maghreb countries

Country	% of coastline subject to erosion	% of coastline urbanized	Long-term Erosion	
			Rate	Area
			(m/yr)	(Ha/year)
Algeria	29%	14.5%	-2.1	-90.5
Libya	55%	7.0%	-0.9	-100.1
Morocco	54%	6.6%	-0.9	-139.9
Tunisia	59%	15.0%	-2.4	-247.3

Source: Authors based on Luijendijk et al (2018)

[4] *We rely on the global dataset provided by Luijendijk et al (2018) to quantify the direct costs of coastal erosion in Maghreb as the novel dataset on coastal erosion presented in Section 3 currently covers only the Moroccan and the Tunisian coastline. With the extension of the coverage, the empirical exercise could of course be refined in future work.*

[5] *This also leads to the differences in values for coastal erosion reported in Table 1 and the ones depicted in Figure 3 in the previous section.*

In order to quantify the value of land lost, the unit price of coastal land per square meter in these countries was assessed, based on market data and, where available, official statistics.[6]

Prices of land near the coast differ substantially based on its location. Urban prices for coastal land exceed the ones of rural areas considerably, due to the limited space in cities following high rates of urbanization and exuberant demand for nearshore properties within them.[7] Table 2 shows the result of these assessments. Urban land is most expensive in Morocco, while being comparatively lower in Algeria. Rural land prices are not as dispersed, ranging from USD20 per square meter in Morocco and Algeria to USD30 in Libya. The present value of annual rents for the next 30 years is then used as an estimate of the value of land. Some assumptions had to be made for the calculation of the present value of land. The rent-to-price ratio of land was assumed to be 8 percent with rents increasing by 8 and 5 percent for urban and rural land, respectively. To account for agglomeration effects in coastal regions, average urbanization rates as estimated by the United Nations for the 30 years were used. Finally, a standard rate of 3 percent was used for discounting future rents foregone by erosion of coastal areas.

Table 2: Coastal land prices for Maghreb countries (US$/m2)

Country	Urban	Rural
Algeria	350	20
Libya	480	30
Morocco	650	20
Tunisia	450	25

Source: Authors based on rapid price assessment

The distinction between prices of land due to its location necessitates the classification of eroded land due to its land use.

We used the European Space Agency's Global Land Cover database [8] to determine the share of urban areas on the total coastline. Column 2 in Table 1 provides the results of this exercise. More than 15% of Tunisia's and 14.5% of Algeria's coasts are urbanized respectively. For the other countries the share of urbanized coastal area is lower, with 7% in Libya and 6.6% in Morocco.[9] To estimate the value of built housing assets destroyed per year, estimates for the average replacement costs of buildings for coastal districts, adapted from data for twelve countries in the MENA region (Dabbeek & Silva, 2020). The number of dwellings, buildings and population is identified on a very fine scale and the economic value based on geographical location and physical characteristics is estimated. Aggregating these data for coastal districts in the four countries under investigation allows for the estimation of the value of lost assets due to coastal erosion.[10]

Table 3: Direct economic costs of coastal erosion

	Algeria	Libya	Morocco	Tunisia
Buildings lost (US$ million)	3	1	8	29
Land lost (US$ million)	310	272	425	1,078
Total (US$ million)	**313**	**273**	**434**	**1,107**
Total (% of GDP)	**0.2%**	**0.7%**	**0.4%**	**2.8%**

Source: Authors.

Direct costs of inaction with respect to coastal erosion in Maghreb countries are high.

Table 3 provides the estimates regarding average yearly direct costs arising from inaction to coastal erosion processes based on values for lost land and buildings upon it. The estimates show that in Maghreb countries coastal erosion entails substantial direct costs, ranging from USD273 million per year in Libya to more than USD1.1 billion per year in Tunisia. To put this into perspective, relative to the gross domestic product, in Algeria the damages and losses amount to about 0.2% of GDP, in Morocco to about 0.4% of GDP, in Libya to about 0.7% of GDP and in Tunisia to about 2.8% of GDP.

However, these costs only represent a lower bound on the total costs arising from coastal erosion and its effects by not explicitly considering reductions of economic flows.

It should be reiterated that the costs presented here provide a conservative estimate of the lower bound on total costs arising from the degradation of the Maghreb's coasts. Considering that coastal areas are hotspots of economic activities and that coastal erosion can be a serious impediment for their well-functioning, it can be expected that continued degradation of coasts has severe repercussions on them. Capturing these costs accurately would provide highly valuable insights in the total coasts of coastal erosion but necessitates detailed assessments of tourist behavior, business surveys and similar studies, preferably on a local scale. Some options of such analyses are discussed in the next section.

Furthermore, the estimates of the direct costs of inaction provided are also conservative as they are not taking into account losses in adjacent properties.

Near-shore properties derive part of their value from their proximity to the sea and hence may be affected indirectly in a sense that their value will be reduced even if erosive forces do not directly destroy them (Scott et al, 2012; Pompe & Rinehart, 1995; Fraser & Spencer, 1998). A detailed study on erosion management strategies at the East Coast of the US finds, using a hedonic price model, that the value of property is substantially lowered if located in a high-erosion zone (Landry et al, 2003). The negative effect of beach retreatment on property values diminishes with distance, implying that properties that are near but do not necessarily border the shore can be affected through negative spillover effects arising from erosion processes (Rinehart & Pompe, 1994). These effects are not included in the estimates of direct costs presented above, one more reason tha they should be viewed as rather conservative assessments of the overall costs due to coastal erosion in the countries under scrutiny.

[6] *The various sources are either online property portals (such as avito.ma, mitula.ma, homeintunisia.com, opensooq.com with various country domains) or official sources where available (mainly in Morocco).*

[7] *It should be noted that it would be preferable to further distinguish between agricultural land and building plots in the case of rural land. However, additional to price data constraints, determining the relative shares of these types of land on total rural coastal area proved to be hardly possible. While the land use dataset of the ESA provides a distinction for already built-up areas and ones that are explicitly used for agricultural purposes, it is not possible to determine whether a certain plot of bare land is dedicated as a building plot or not. Given these difficulties and the often not clear-cut rules for land classification in these countries, we refrain from drawing such distinctions and use a composite price for rural areas.*

[8] *http://www.esa-landcover-cci.org/*

[9] *The share of urban areas are calculated for the whole coastline, not only for the parts that are subject to erosion. The limited information for land prizes did not allow for such a differentiation.*

[10] *Note that these estimates do not take infrastructure costs (e.g. lost roads) explicitly into account.*

The effects on developments such as ports or industrial sites as well as on ecosystems are most likely substantial but also hard to quantify.

Besides destroying buildings, coastal erosion also impairs the human developments along the coast such as ports or industrial sites. Conversely, the construction of harbours or other coastal infrastructure could also exacerbate coastal erosion elsewhere, as was for example the case for Algeria's heavily developed coast (Bouhmadouche & Hemdane, 2016). Furthermore, coastal erosion has also detrimental effects on the coastal ecosystem, destroying the habitat of coastal flora and fauna. These specific effects are not captured in the analysis above as it would require detailed modelling of effects and costs of coastal erosion along these developments and natural habitats, a task that is hardly possible at a national or regional scale.

Climate change will increase direct costs that arise from coastal erosion in the future.

The impacts of climate change such as a higher probability for extreme weather events and advancing sea level rise will exacerbate coastal erosion and its effects. Hence, the costs due to this phenomenon will also most likely increase in the future unless suitable steps are taken to combat it and protect human developments where possible.

Nonetheless, this empirical assessment shows that shore retreatment is a substantial threat and entails significant direct costs for the affected regions when no action is taken.

Advancing sea level rise and a higher probability for extreme weather events due to the effects of climate change will most likely culminate in even higher costs in the future. Immediate action should thus be seen as indispensable, both to mitigate direct costs now and in the future with their associated impacts on coastal populations, many of which are dependent on intact shores for their basic income.

Reduction of economic revenue generated from tourism in coastal areas

Direct losses due to coastal erosion are only a fraction of total losses to the economy, not considering the impact on tourism or marine activities as well as ecosystems.

The analysis on direct costs of coastal erosion presented in the previous section provides only a very conservative estimate about the actual costs of this phenomenon in Maghreb countries. Accounting for lost future revenues, accruing mainly in the tourism sector, is crucial for assessing the real costs of coastal erosion, also with respect to potential losses in tax revenues. Furthermore, coastal erosion processes can also impair the revenues generated in ports and near-shore industries dependent on intact coasts. Another important point to consider is that ecosystems may be permanently damaged from coastal erosion, which can be important income sources, such as for fisheries. While incorporating these aspects would be beyond the scope the current report, this section gives an overview of how economic flows are impacted, with a main focus on the effects of coastal erosion on tourism. It furthermore also sheds light on some of the methodologies that can be used to assess the magnitude of those indirect costs.

Coastal erosion and its impact on economic flows generated by tourism

Incorporating the indirect effects of coastal erosion that arise from reduced economic revenues is crucial for the accurate determination of total costs attributable to the phenomenon.

Having estimated the costs in terms of lost land and destroyed buildings in the last section, it should be reiterated that these estimates are only capturing a certain portion of the total costs that stem from retreating coasts. Probably the largest share of the costs of coastal erosion, especially in the long-term, will be by reducing revenues resulting from touristic activities in areas that are impacted in the sense that assets from which economic flows are derived are destroyed and hence future flows are lost.[11] Foregone revenues from tourism activities are a severe threat, especially for countries for which "blue" tourism represents a large part of their revenues. Furthermore, erosion of coasts, but also accretion in certain parts, can have negative effects for other coastal activities such as impairing transportation pathways in ports or making crucial infrastructure unserviceable and hence reducing value added derived from them. Especially Algerian international trade (mostly in the form of hydrocarbons) is dependent on ports, with 95% of international trade and 98% of hydrocarbon exports leaving Algeria by sea.[12] In Libya, ports are similarly important for oil exports but their operations have been negatively affected by political unrests, with several important ones temporarily closed for months at the time of writing, including the largest oil export terminals in Es Sider, Zawiya and Ras Lanuf.[13]

Coastal erosion is an existential threat to tourism, a sector than contributes significantly to economic output in Maghreb countries.

For example, both Tunisia and Morocco are heavily dependent on their tourism sector, which to a large part builds on the existence of beaches. In Morocco over 12 million international visitors were recorded in 2018, with receipts received totaling more than $9.5 billion (around 8% of GDP) according to data from the United Nations World Tourism Organization (UNWTO) and tourism activities account for more than half of export in services.

Considering indirect economic impacts, tourism and its value chains accounted for 18.6% of GDP and 16.4% of employment in 2017 (Kasmi et al, 2020). In Tunisia, economic activity connected with the tourism sector amounted to 14.2% of GDP in 2018, offering job opportunities for more than two million Tunisians.[14] Receipts received from international tourists alone contributed over $2.3 billion to the economy, representing around 6% of GDP in 2018 and more than 90% of the country's recorded bed nights were spent in coastal areas (Jeffrey & Bleasdale, 2017). Tourism is less developed in Algeria and Libya and has had some setbacks in the recent past due to political unrests. However, the Algerian government is looking for ways to attract international tourists, aiming to increase annual international tourist arrivals to 5 million by 2025.[15] Hence, the imminent threat posed by the disappearance of beaches due to coastal erosion for tourism in the region should be recognized.

---

[11] Ghermandi and Nunes (2013) provide estimates for the value of recreational services for near-shore locations on a global scale and show that these vary with the accessibility, development and touristic amenities like the existence of beaches or coral reefs.
[12] https://oxfordbusinessgroup.com/overview/modernisation-route-capital-investment-boost-transport-infrastructure-continues-despite-lower
[13] https://www.bloomberg.com/news/articles/2020-09-23/libya-restarting-oil-exports-at-a-third-port-as-conflict-abates
[14] https://english.aawsat.com//home/article/1840766/tunisia-13b-tourism-revenues-expected-2019
[15] https://www.arabianbusiness.com/travel-hospitality/440174-algeria-looking-to-open-its-tourism-doors-to-the-world

Tourists primarily visiting the coasts of the Maghreb could decide not to return should beaches disappear.

There are several drivers that could drive negative indirect effects. In the extreme case, disappearance of beaches could lead to total losses should tourists decide not to visit the affected areas at all anymore. For example, for some tourist groups a majority of respondents to a survey conducted in a Hawaiian town stated that they would not consider staying in a hotel should the nearby beach completely erode (Tarui et al, 2018). Similarly, more than three quarters of surveyed tourists in Barbados were unwilling to return for the same price should beaches largely disappear; this was associated with a 46% decrease in tourism revenues. Other environmental features also drive the willingness of tourists to return in nearby Bonaire, with again more than three quarters of them not willed to return for the same price should corals bleach (Uyarra et al, 2005). For two stretches along the Australian coast, large parts of tourists stated that major erosion events would lead them to switch to other destinations; losses equated to more than USD75 million per year (Raybould et al, 2013). Hence, the retreatment of beaches could lead to severe economic losses, especially in regions that are primarily visited for their beaches.

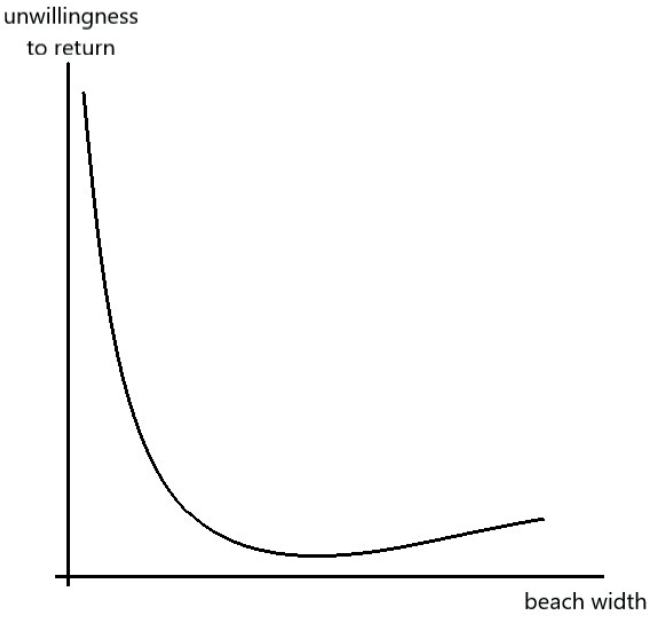
The propensity of tourists to visit a certain location decreases due to beach retreatment, but not necessarily in a linear fashion.

There is broad consensus that the retreatment of beaches is lowering the willingness of tourists to return to locations that are primarily relying on beach recreation, with the extreme case of visitors not returning should a beach erode completely (as discussed above). For example, in a survey carried out at beaches in Delaware, United States, around two third of visitors stated that a reduction of a beach's width to a quarter of its current size would worsen their experience and a third indicated that they would reduce their number of visits (Parsons et al, 2013). Similarly, for Californian beaches it was found that visits to beaches are negatively related with losses in beach width due to coastal erosion, however in a non-linear fashion and differing by main activity of tourists coming to the beach. For beaches that are narrower than 20 meters, a reduction in width is associated with much larger decreases in the propensity of recreational visitors to come back than when initial beach width is larger than 20 meters (Pendleton et al, 2012).

In Barbados it was found that tourist's aversion to return is especially strong for beaches with a width of less than 8-10 meters (Schuhmann et al, 2016). However, interestingly beaches can also be too wide, with long ways to the sea decreasing visitor's utility (Parsons and Massey, 2003; Pendleton et al, 2012). A similar non-linear relation can also be found for the speed of erosion, where surveys reveal that higher rates of beach retreatment lead to a disproportionate reduction in consumer surplus, and hence propensity to revisit, compared to slower retreatment rates (Huang et al, 2011).

These findings imply that the relationship between the unwillingness to return of tourists and the beach width can be thought as approximately having a shape like the one depicted in Figure 4.

Figure 4: Stylized relationship between beach width and unwillingness to return



Source: Authors.

Having intact beaches is an important determinant for the prices hotels can charge.

In coastal districts a higher share of open or flat coastlines (i.e. beaches) is a significant determinant for higher accommodation prices (Hamilton, 2007). In a similar spirit, hotel prices at Costa Brava in Catalonia of those having a beach awarded with the Blue Flag certification in their vicinity are more than 10% higher on average (Rigall-I-Torrent et al, 2011). Blue Flag certification indicates that the beach and sea water quality meets certain standards and that beach management also fulfills specific environmental standards. Both Morocco and Tunisia are part of this program and efforts to extend its scope are ongoing in order to accommodate to changing attitudes of tourists. Revenues for hotels in the vicinity of retreating beaches are likely to decrease, as the amenity value for tourists decreases if the beach quality deteriorates.

Options for assessing the impact of coastal erosion on touristic economic flows

There are different approaches to assess the effects of coastal erosion on touristic flows and most of them were scarcely applied in the Maghreb.

Scientific studies in the literature employ different methodologies to assess the costs of coastal erosion in terms of lowering tourism revenues or value of touristic places and properties. Some of those are based on survey information, while others include physical characteristics of beaches and their amenities. What unifies them is their rather sparse application in Maghreb countries, impairing the reliable assessment of the total costs stemming from coastal erosion. Hence, further research in this area is called for.

One way to estimate the indirect cost of coastal erosion is by asking individuals about their preferences with regards to avoiding the erosion of beaches and asking them to monetize them.

A common way how this issue is addressed in the literature is to utilize surveys to determine what is called the "willingness-to-pay" (WTP) of both residents and tourists to preserve beaches. This measure reflects the amount of money that these people would be willing to pay for beach-saving initiatives such as beach nourishment or building offshore safeguards. The reasoning behind these studies is that, while such measures can be quite costly (also varying with respect to the region) ex-ante, ignoring those possibilities may lead to much higher ex-post costs induced by sea level rise and costal erosion (Darwin and Tol, 2001). The nature of these surveys, which build to certain extent on the attachment of respondents to the region under scrutiny, limits their practical use to small geographical units such as individual beaches or beaches on a certain island.

However, their importance with regard to informing policymakers about possible sources for financing of such precautionary measures is not negligible and some lessons can be drawn from such analyses. They can also be used to assess different threats for the attractiveness of assets like beaches. For example, one such study found that beach retreat has a diminishing influence of beachgoers utility of beachgoers on average and that the WTP to avoid beach retreat is higher than for beach closure due to jellyfish outbreaks or the loss of seagrass in the surrounding water (Enriquez & Bestard, 2020).

Studies have shown the potentially high losses of touristic revenue stemming from coastal erosion in the Maghreb.

For example, tourists visiting Djerba Island in Tunisia would be willing to contribute over €5 million a year for a project aimed at reducing coastal erosion (Dribek and Voltaire, 2017). This figure implies that beach preservation measures to reduce coastal erosion may be financed largely by contributions by tourists[16] and also measures the value that tourists attribute to intact beaches. Hence, considering that most of the Djerba's tourism is focussed on its coastal zone (Widz and Brzezinska-Wojcik, 2020), an erosion of its beaches may in fact eradicate tourism altogether, implying huge potential revenue losses.

While this may seem like a local example for costs of beach retreatment, it should be noted that Djerba hosts around 25% percent of international tourists visiting Tunisia (Carboni et al., 2014), exemplifying its important status for the Tunisian tourism sector as a whole. For a similar region in Morocco, the Tetuan coast with its main touristic beaches, Benkhattab et al. (2020) find that total eroded surface in the period from 1958-2018 amounted to approximately 490 ha. Building on these numbers and the projections about beach retreatment in the future, Flayou et al. (2017) estimate that lost revenues to the economy due to the retreatment of these beaches alone could accumulate to USD190 billion in the next few decades.[17]

Other approaches that quantify the economic effects of coastal erosion also highlight large potential losses to the local economy.

They may use information on the attributes of beaches like their width, land value and characteristics of hotels located nearby (e.g. room price) to directly estimate reductions of land values and revenues due to coastal erosion in the framework of hedonic price regressions. Using such an approach, the decrease in beach width due to coastal erosion in Rethymnon on the Greek island Crete could lead to revenue losses amounting to around EUR18.5 million in the next ten years due to the progressing retreat of a single beach (Alexandrakis et al, 2015). The impact of sea level rises on beach tourism in Sahl Hasheesh and Makadi Bay, Red Sea in Egypt were valued to lead to expected losses in revenues that could exceed USD350,000 per day in 2050 (Sharaan et al, 2020). Similar studies show beach surface reduction to have a decisive negative impact on the overall image of tourist destinations, decreasing the number of arrivals and hence reducing receipts received from them (Scott et al., 2012; Raybould et al., 2013; Bitan and Zviely, 2019).

The importance of economic flows and the scarcity of available evidence to build on in the Maghreb highlight the needs for further research in this area.

To base policy decisions on firm evidence regarding the total costs of coastal erosion, it is hence imperative to understand the impacts of this phenomenon on economic flows. Identification of these indirect costs relies on local assessments of different factors including the willingness-to-pay for protective infrastructure as a proxy of foregone revenue and closer insights in the spatial distribution of economic flows along the coast and how they could be affected by coastal erosion. By highlighting the potentially huge losses in the tourism sector alone, this report argues for more locally focussed research to clearly understand these potential costs in order to derive suitable policy responses where possible. This includes surveys among residents as well as tourists, detailed stock-taking of economic activities along the coast and assessing the extent how coastal businesses are already affected now and what threats the continued process of coastal erosion could pose to them. Such studies should be conducted in cooperation with local authorities but also other institutions such as universities and include all relevant stakeholders in order to provide an holistic assessment of total costs attributable to the degradation of the Maghreb's coasts.

A novel dataset on changes of the coasts in Morocco and Tunisia

The efficient identification of coastal erosion hotspots requires fine-scale investigations of the coast on a large scale. However, the respective coast segments that are under threat of eroding also have to be observed at a level that is as granular as possible. This section presents the findings of such a detailed analysis that was carried out for the coasts of Morocco and Tunisia in cooperation with the National Oceanography Centre of the United Kingdom. In order to accurately determine the extent of coastal erosion of certain hotspots, for this analysis only high-resolution satellite photographs were used and several enhancements to the workflow

[16] *The authors also calculate the willingness-to-pay for the project residents of Djerba residents and found similar values per capita. As the number of residents (around 30,000) is tiny in comparison of tourists visiting Djerba (more than one million per year), the contributions of tourists are the lion's share of overall contributions.*

[17] *It should be noted that the authors compute these highly detrimental effects to the local tourism sector by means of benefit transfers of WTP values from another source and assume a complete disappearance of the beaches, a process that varies for the different beaches under scrutiny and may in fact take several decades. Nonetheless, these findings highlight the potentially huge amounts of losses that could result from coastal erosion for touristic regions.*

were proposed to refine the resulting database. Additionally, the width of analyzed segments along the shoreline is considerably lower compared to previous studies. These granularities in the analysis process allow for very precise assessments of hotspots of coastal erosion along the whole coastline under scrutiny, providing novel evidence of coastal erosion hotspots. The first subsection provides an overview of changes in the coasts of Morocco and Tunisia, identifying regions that gained or lost area in the last decades. The next subsections then demonstrate the merits of using high-resolution satellite photos to conduct a detailed study of the coastal landscape. In particular, the second subsection assesses changes of certain Tunisian beaches that exhibited severe rates of erosion in the past and were defined as priority areas given their importance as touristic destinations. The third subsection exemplifies the forecasting possibilities of the analysis carried out. The last subsection then illustrates the effects that different protective measures have on the coast they are intended to protect.

Identifying coastal erosion hotspots in Morocco and Tunisia

While coastal erosion takes place globally and at national scales, understanding the specific drivers of coastal erosion at a local scale is important.

While the analysis above provides an estimate of the costs of coastal erosion at a national scale for the four Maghreb countries under scrutiny, it is important to note that changes in the shoreline are highly case-dependent, with erosion and accretion site often closely together, sometimes even at the same beach. These local differences require large-scale, yet granular analyses of shorelines to cover a country's coastline comprehensively to identify coastal erosion hotspots, while also allowing accurate assessments of the dynamics at a more local scale.

Small-scale differences can make a difference; hence, higher resolutions of coastlines are preferable.

It is clear, that aggregate national indicators can hide a lot of the heterogeneity within countries, where some local areas are eroding as others are accreting. Similarly, analyses using finer resolutions for the identification of these processes at shores can provide important insights of historical processes as well as help quantifying erosion rates that can be expected in the future. Hence, to better understand regional and local erosion rates in Maghreb countries, a cooperation with the National Oceanography Centre of the United Kingdom and the European Space Agency has been put forward to better understand the distribution of coastal erosion along the coast (NOC, 2020). This task was achieved by employing higher resolution spatial images from satellites launched no earlier than 2000, where 50m segments as opposed to the 500 meter segments of the coast from Luijendijk et al (2018) or 250 meter segments from Mentaschi et al (2018) were used.

Refined workflow adjustments for many potential error sources greatly enhances data quality.

The analysis carried out by the National Oceanography Centre included a sophisticated workflow to minimize potential error sources and increase accuracy compared to previous studies on a global level. It included processing of high-resolution images from several satellites that were synchronized and pre-processed to account for cloud masking and pansharpening[18] the data. Through machine learning techniques images were classified and additional error sources removed. For example, in contrast to Luijendijk et al (2018), the analysis accounted for issues related to possible misclassifications of shorelines due to white-water, a phenomenon that occurs from breaking waves as they approach the shore and is one of the largest error sources in shoreline classifications (Pardo-Pascual et al, 2018).[19] After casting the refined transects, change rate statistics were calculated and future shoreline changes predicted. The analysis was carried using historical coastal erosion data in the time period 2000-2020, providing estimates for a more updated timeframe than Luijendijk et al (2018), with forecasts available for the 10 year and 20 year horizon, providing information about future changes at policy-relevant timeframes. A background paper (NOC, 2020) provides more details on the methods used, the implementation of the various verification steps and other technical details.

Some challenges remain in the use of remote sensing for the assessment of coastal erosion.

Even though the present analysis makes substantial headway to improve the accuracy of, a few caveats remain and should be acknowledged. First, the accuracy of the estimates hinges on the number of images made of each shoreline. While there is sufficient data for an determination accurate most of the times, some parts of the coastline has been less well covered than others, potentially leading to problems to account for tidal changes. Ongoing efforts to utilize even more images will remedy this problem in the future. However, the usage of different satellites opens up the possibility for discrepancies. While this has been addressed through a co-registration process, occasional differences may prevail. Lastly, some issues arise for transects that are cast in river inlets or low-lying, intertidal areas that are too distant from each other to be cast in one transect. The complex nature of such areas makes it difficult to capture change rates over time accurately, requiring more thorough analysis of transects in these areas. While considerable effort has been put into accounting for these issues, some potential for errors remains.

There is also temporal variability in coastal erosion processes, with aggregate statistics potentially masking them.

Additional to the specificities of different geographical locations, coastal erosion processes, such as the response of sandy beaches to sea level rise, are also temporally variable (Cooper et al, 2018). Given that shorelines are constantly subject to changes – whether they are induced by human development or natural forces - regular monitoring on a granular spatial scale is important to consider variabilities in all dimensions in order for policy-makers to be able to make informed choices based on accurate and timely evidence. The nature of the analysis carried out by the National Oceanography Centre allows for considering the long-term historical changes of the coastlines at a very granular spatial scale but also a detailed analysis of changes in erosive processes over time. Using this information not only can policy-makers base their decisions on current developments along the shore, but also already implemented protective measures can be evaluated with regards to their effectivity in curbing the threat of coastal erosion to human developments and their potentially unintended side-effects.

[18] *Pansharpening is a process of lowering the resolution of a multispectral image using a higher-resolution panchromatic band.*
[19] *It should be noted that the analysis by the National Oceanography Centre does not involve a in-situ assessment of shoreline changes, i.e. the results are not verified on-site.*

For Tunisia and Morocco, these detailed analyses already allow for more accurate identification of the local hotspots of coastal erosion, with more countries to follow.

In a first step, the National Oceanography Centre carried out detailed analyses of the coasts of Tunisia and Morocco; two countries whose coasts are threatened by coastal erosion and for which beach tourism and coast-related activities play a very large role in their economic mix. Moroccan statistics are split into Atlantic/Mediterranean at the Ksar es-Seghir port, as it was expected that there may be a difference in the nature of shoreline evolution due to hydrodynamic processes at the coast. The analysis has shown that coastlines facing the Mediterranean have lower sandy coastlines; with Morocco showing 75% and Tunisia 85%, whereas the Atlantic side of Morocco's coastline demonstrates a near-complete sandy composition at 96%.

Even though overall more areas in Morocco and Tunisia erode, changes in the coastal landscape are also heterogeneous with respect to the speed at which they change.

An overview of the different forces shaping the coastlines of Tunisia and Morocco can be gained by comparing the percentage of areas undergoing different shoreline dynamics (Figure 5). For both countries eroding areas (i.e. ones loosing at least 0.5 meter per years in the past decades) are exceeding the ones that experienced varying degrees of accretion. Tunisia illustrates a relatively evenly balanced shoreline change for each category but more than 35% of Tunisia's beaches are eroding.

Around 38% of the Atlantic Moroccan coast is eroding to some degree, with about 28% accreting. On the Mediterranean coast of Morocco classes of erosion and intensive erosion are 4% more than the respective classes of accretion. Overall, it is characterized by more balanced, but also more dynamic erosion patterns, with only around one quarter of the shore remaining stable in the past two decades.

Comparing the changes derived from the novel study to ones of global assessments reveals some differences in coastal dynamics detected.

When comparing these shares as well as the resulting average net erosion rates with the ones on the global dataset provided by Luijendijk et al (2018) that are depicted in Figure A1 in the appendix, some differences between them are worthy of deeper reflection. First, for Tunisia larger parts of the coastline were found to be eroding in the global dataset compared to the novel dataset, with the largest discrepancies in the category of extreme erosion (i.e. erosion at a rate larger than 5 meters per year). On the other hand, based on the more granular data provided by the NOC a substantially larger part of the shoreline has intensively been accreting area (i.e. with rates between 1 and 3 meters per year) than estimates from Luijendijk et al (2018) suggest. Conversely, Morocco's coasts, both the Atlantic and the Mediterranean one, have been classified as being more stable (i.e. neither eroding nor accreting at a pace faster than 0.5 meters per year) in the global exercise conducted by Luijendijk et al (2018) compared to rates computed by the NOC. A notable exception is the much higher share of extreme erosion along the Mediterranean coast.

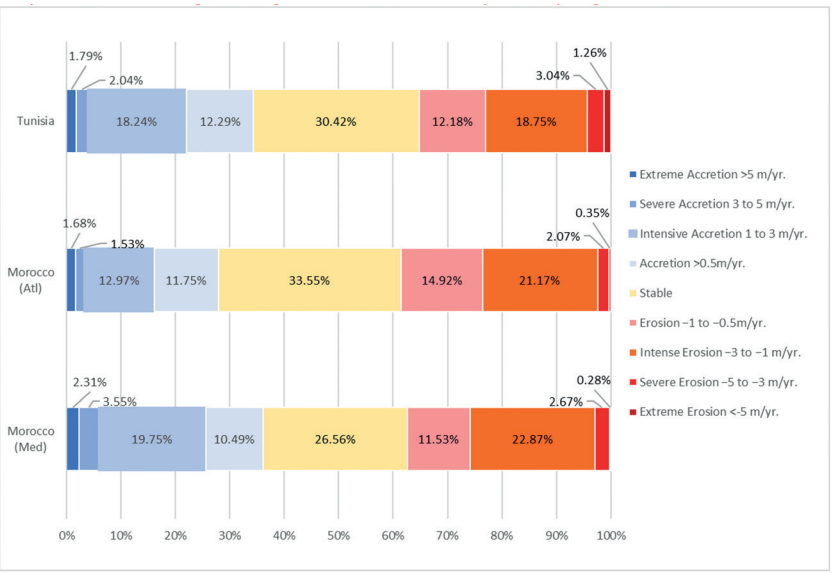
There are different factors that could drive these discrepancies. For once, the time period under investigation differs across the studies, even though there is considerable temporal overlap. Generally, the somewhat smaller erosion rates in the new dataset for Morocco and Tunisia could indicate erosion trends have decelerated in the last two decades, compared to the period before 2000, even though erosion still remains high. The higher granularity of the new dataset and the more advanced methodologies used to correct for some of the mismeasurement errors are other plausible sources for discrepancies. This highlights again the usefulness of the presented study as more precise identification of coastal erosion hotspots can aid policy-makers to funnel scarce resources to protective measures in those regions that are affected most strongly by their eroding coastlines.

The detailed analysis of Morocco's and Tunisia's shorelines allows for assessing the effects of coastal erosion more closely.

In the following paragraphs illustrations of the shoreline change are provided. In the figures to follow, the data of the individual 50m transects are presented by aggregating the data to hexagons to better visualize the data.[20] The colors of the individual hexagons indicate the change predominant in certain regions, with red hexagons indicating erosion and blue ones accreting areas. Yellow hexagons denote relatively stable parts of the shoreline.

Figure 5: Shoreline changes are very heterogeneous within Tunisia and Morocco

Proportion of accreting, eroding and stable shoreline by country/region



Source: Authors.

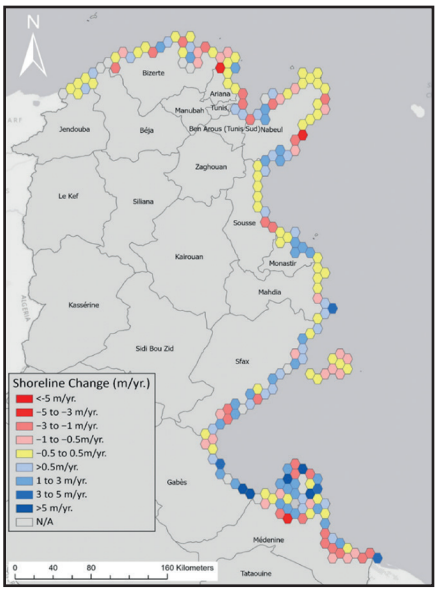
[20] *Hexagons represent the shape and direction of the coastline whilst reducing sampling bias (Sahr et al., 2003). After experimentation, a 15km² hexagon was deemed suitable for Morocco and 50km2 for Tunisia, to summarize a mean shoreline change rate over the three areas.*

Coastal erosion in Tunisia.

As indicated above, shoreline changes are hugely varied within countries and this is also the case in Tunisia (see figure 6), for which 85% of the coastline was identified as being sandy. Intensive erosion, i.e. beaches receding by more than 2 meters per year, is mainly happening in seven main areas with Utique in Bizerte and Korba in Nabeul. The highest accreting areas are located along the coast of Sfax, Gabes and Medenine, the latter of which frequently experiences extreme or severe accretion. Whilst the state of shoreline change is mixed, there appears to be more erosion occurring in the North, with more accretion in the South.

Figure 6: Many beaches in Tunisia are eroding

Hotspots of coastal erosion



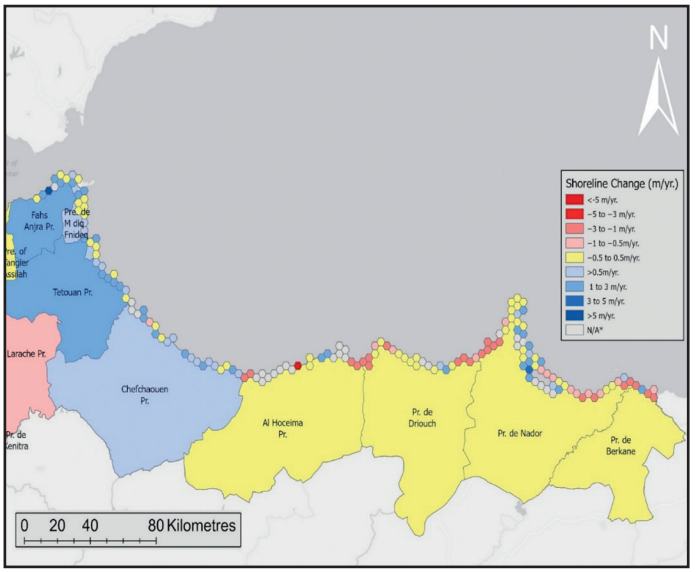
Source: Authors.
Note: Tunisia shoreline change rates aggregated to about 50km^2 hexagons.

Erosion of Morocco's Mediterranean coast is characterized by the influence of human structures.

On Morocco's Mediterranean coast, intensive accretion is occurring in the Fahs Anjra and Tetouan Provinces (Figure 7). Anthropogenic developments such as Northern Africa's largest port, Tanger-Med, a 1.6km^2 long strip of development on the northern tip of Morocco, are likely to have a significant and potentially ongoing effect on shoreline change rates. A further possible source of change relates to the hydrological cycle and the rates of river flow deposition at estuarine locations. This has not been investigated but these are inherently variable systems which may experience significant interannual and decadal variability. In spite of this, it seems unlikely since there are numerous studies on the threat of the Moroccan coastline due to sea level rise (Snoussi et al., 2008; Snoussi et al., 2009; Kasmi et al., 2020). Further along the Mediterranean coast of Morocco, erosional processes become more dominant. The largest sections of erosion are occurring on either side of the Driouch Province in the Al Hocaeima bay Port and surrounding the Port Nador West Med. A combination of mis-registration issues and coastal infrastructure developments are resulting in the severe accretion rates within the lagoon at Nador. However, along the outer coast of Nador intensive erosion is occurring. The coastline is migrating landward and the beaches are insidiously shrinking, posing a threat to their sustainability.

Figure 7: Shoreline changes along the Mediterranean coast of Morocco

Hotspots of coastal erosion



Source: Authors.
Note: Morocco Mediterranean shoreline change rates aggregated to about 15km^2 hexagons.

Large parts of the Atlantic coast of Morocco are also eroding.

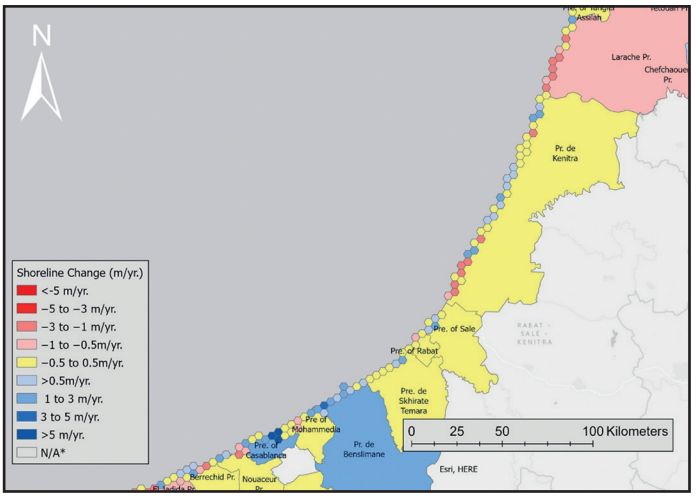
Along Morocco's north Atlantic coastline, erosion is common in the Larache and El Jadida Provinces (Figure 8 below). Intensive erosion is also occurring in regions of Kenitra and Nouaceur. Pockets of severe or extreme accretion can be found around the port in Casablanca and the headland at Mohammedia, Guelmim Oued Noun, but accretion is also dominant across the northern Mediterranean tip of Morocco.

Larache is a coastal town on the south-west side of Tanger-Tétouan-Al Hoceïma where a mix of morphological processes are occurring with reports of considerable sand mining activities.[21] Investigations into the shoreline change rate along the Tetouan coast using aerial photographs showed the shorelines retreated by an average of 58.4m over a 60-year period (Benkhattab et al, 2020). With the boundaries of intensive erosion ranging from -1 to -3 meters per year, erosion appears to be increasing; in another 60 years it is projected to retreat by a further 60 to 180m.

[21] *https://coastalcare.org/2015/10/the-sand-thieves-of-larache-northern-morocco*

Figure 8: Shoreline changes along the Atlantic coast of Morocco

Hotspots of coastal erosion



Source: Authors.

Note: Morocco Mediterranean shoreline change rates aggregated to about 15km2 hexagons.

Zooming in on selected hotspots of coastal erosion in Tunisia

More than a third of Tunisia's sandy beaches are under threat from coastal erosion, with some experiencing erosion of several meters per year.

Around 35% of Tunisia's sandy coastlines are eroding at a rate of more than 0.5 meters per year (see Figure 5 above). Given their importance for the tourism sector as well as the threat coastal erosion poses for them, this report identified and defined three beaches in Tunisia as priority areas. These beaches were among those parts of the coast that experienced the starkest reductions in the recent past and are threatened by further retreat in the future. However, it should be stressed that this also holds for many other beaches in Morocco and Tunisia, making timely action to combat their retreatment indispensable.

One such beach that is declared a hotspot for erosion is located in Hammamet Bay, south of the capital in central-east Tunisia.

Coastal erosion at the Hammamet beach contributed to the loss of 24,000 square meters of beach area in the span of thirteen years between 2006 to 2019 with a loss rate of 3-8 m/year (see figure 9). These high rates of erosion are in large parts caused by the rapid urbanization on the coast of Hammamet that hinders natural sediment from flowing to the shoreline. Coastal erosion manifested by shoreline retreat along with the rapid urban growth has also negative effects on groundwater aquifers and vegetation coverage as it made aquifers exposed to seawater intrusion (Amrouni et al, 2019).

Figure 9: Coastal erosion Hammamet beach, Tunisia

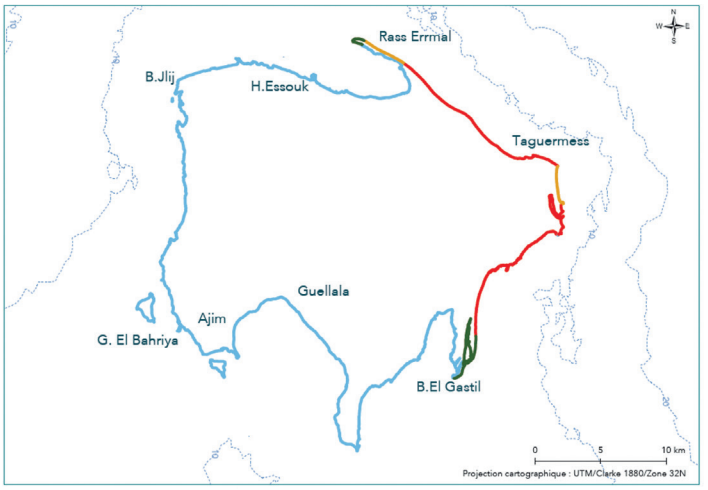
Source: Authors.

Note: in orange is the beach as of 2019 and in green is the beach as of 2006.

Beaches of Djerba island, a major tourist destination, also have been on the fast retreat.

Figure 10 below shows that large parts of the eastern shoreline of Djerba island, located in the Southern part of Tunisia and a highly touristic island that hosts around a quarter of all international tourists visiting the country (Carboni et al, 2014), have been eroding in the past decades (as documented for example in Oueslati, 2015).

Figure 10: Coastal erosion Hammamet beach, Tunisia



Source: Oueslati et al (2015)

Note: Red parts of the coastline denote areas experiencing erosion, green parts are accreting and yellow parts are rather stable.

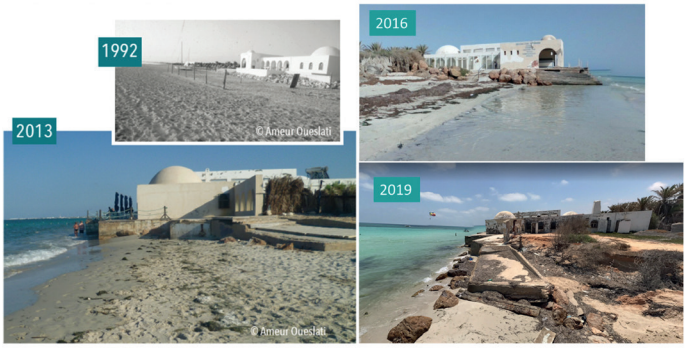
Specific locations on Djerba have massively lost beach area in the last decades.

Such a location is the beach at Dar Djerba that has lost an area of around 6,900 square meter in the period from 2003 to 2018 (see Figure 11). This potentially has negative repercussions for the nearby tourist resorts deriving most of their amenity for tourists from intact beaches and threatens the local economy that is heavily dependent on tourism overall. The advanced state of beach retreatment and its effects on coastal resorts has also been impressively observable for certain site, e.g. for the oceanfront of the Les Sirenes hotel (Figure 12). Since the 1990s the beach on front of the hotel has basically disappeared and progressing coastal erosion has damaged parts of the resort, leading to the abandonment of it. Between 2006 and 2018, the beach lost approximately 3,500 square meters of its area, implying a loss rate of around 300 square meters per year.

Figure 11: Coastal erosion Dar Djerba, Tunisia

Source: Authors.
Note: Yellow line is the shoreline as of 2003 and red line the shoreline as of 2018

Figure 12: The Les Sirenes Hotel in Djerba, Tunisia



Source: Ameur Oueslati & authors.

Soliman, a village southeast of Tunis, has also seen its beach retreat in the recent past.

The Soliman beach has retreated at a pace of around 3.5 meters per year between 2004 and 2018. Over the course of 14 years, this amounted to an area lost of around 4.3 hectares, the equivalent of more than six football fields. The protective measures that can be seen in Figure 13 below had distinct effects on the sediment transport alongshore and contributed to the erosion dynamics as will be laid out in the next section. The three examples of priority areas in this section represent a few among many such beaches that retreated, highlighting the threat that coastal erosion poses for the Maghreb's beaches.

Figure 13: Coastal erosion Soliman beach, Tunisia

Source: Authors.
Note: Yellow line is the shoreline as of 2018 and red line the shoreline as of 2004

Forecasting future shoreline changes at coastal erosion hotspots

With the aid of high-resolution aerial photographs and predictive models, future shoreline changes can be forecasted based on historical changes.

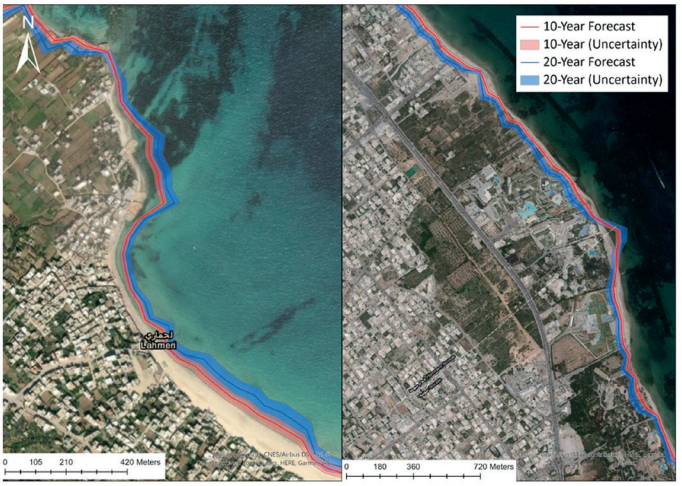
The high resolution of satellite images and the innovative methodologies used to correct for possible misspecification problems in the present study allows for more accurately forecasting future shoreline changes at a very granular level. The forecasts presented here are derived using a Kalman filter, which predicts shoreline changes beginning in the first year (2000) and uses the periods for which observations are available (2000-2020) to iteratively minimize the error of the forecast. This way it improves the forecasts by updating the rate and uncertainty surrounding it on the fly using the historical data, making predictions for future changes (i.e. out-of-sample forecasts) more reliable.

These forecasts can then be used to assess future shoreline changes, both in the form of erosion and accretion, at a local scale and for policy-relevant timeframes.

Having analyzed historical changes at a granular scale allows to accurately forecast future changes of the shoreline at very specific sites. Furthermore, with the aid of the predictive model mentioned above forecasts can be obtained for periods that are most relevant for current policy-makers as opposed to long-term studies on sea level rise and its consequences for coastlines. Such predictions of the shoreline are illustrated below at a local scale (Figure 14). Two cases are present showing severe/extreme accretion and erosion in Tunisia, namely in Lahmeri (left panel) and Hamman Sousse (right panel). The red and blue line show the changes in the shoreline that can be expected in ten and twenty years, respectively, with the shaded areas indicating the uncertainty around these forecasts.

Figure 14: Forecasting shoreline changes in Tunisia

Shoreline change forecast of the mean high-water line.



Source: NOC (2020)

Note: Left = accreting areas in Lahmeri, Tunisia. Right = Eroding areas in Hammam Sousse, Tunisia. Shaded areas denote the 95% confidence intervals of forecasts.

Accurate forecasts such as these can help in designing suitable responses and allow policymakers to make decisions based on more reliable evidence than previously possible.

The case of Hamman Sousse shown above highlights the threat of future aerial loss due to coastal erosion for near-shore human developments. The granularity of the forecasts can be achieved due to the high resolution of the satellite photos used and the fine scale that was chosen to partition the shoreline into segments. This brings about advantages for the reliability of these forecasts for policy-making decisions. For example, when considering the forecasts for Hamman Sousse one can clearly see that certain parts of the coast are expected to erode less than others. In fact, a certain part of the beach is predicted to be accreting in the next two decades, probably due to site-specific dynamics in sediment transport and wave dynamics. This highlights the advantage of using granular data on the erosion of specific sites as opposed to using for example expected rises in sea level alone to model the changes in coastlines. Such analyses are valuable to assess the effects of rising sea levels due to climatic changes on a large scale for different scenarios. However, they are essentially considering only one of the multiple possible sources for coastal erosion and model these effects often for a distant point of time (e.g. the year 2100). Detailed information regarding erosion dynamics for a policy-relevant time horizon are valuable for policy-makers having to decide which parts of the shore to protect and how. Such decisions are associated with substantial costs depending on the specific strategy, making accurate information on near-term shoreline evolution an important factor to determine the most efficient choices.

Additional studies regarding coastal characteristics are important pre-cursors for further increasing reliability of forecasts.

As indicated above, it should be noted as a caveat that the procedure relies on historical erosion rates only and assumes a linear relationship. The utilization of historical data on erosion of specific sites to forecast future changes implicitly incorporates the many different forces that shape the shoreline evolution. However, more explicit modelling of differences in dynamics along the coastlines would be desirable to enhance prediction reliability even further. Furthermore, the current setup does not allow for non-linearities in future erosion. Such non-linearities are however likely to be induced due to a variety of reasons and such as geomorphological characteristics or wave dynamics. For instance, once a sandy beach is eroded further erosion of the coastline made up out of solid material is most likely substantially decelerating. Hence, in order to counter such restrictions and improve forecasting accuracy, additional studies investigating coastal dynamics more closely are needed and would be very beneficial. These include sediment budgets and transport analyses, wave dynamic studies or analyses of geomorphological characteristics, among others. Forces shaping the coast very local in nature, however studying them at a larger scale would allow for the assessment of spillover effects of certain changes in the coastal landscape at one place on others.

Monitoring & Evaluation: the effectiveness of coastal infrastructure interventions

The detailed nature of the analysis also allows for the retrospective evaluation of different protective measures in order to enhance decision processes for future investments.

The granularity of the analysis conducted allows for the comparison with of the effects different protective measures had on coastal erosion processes. Analyses like that are crucial pre-cursors for the design and implementation of future measures that aim to combat coastal erosion at specific sites. This is illustrated here with the example of Soliman beach, which is located in the gulf of Tunis, southeast of Tunis (see figure 15 below). This coastline, in particular, has seen strong rates of coastal erosion through time. To face the effects of the erosion, in the late 1980s, early 1990s infrastructure projects were implemented in the form of breakwaters to protect the natural and urban developments along the coastline (Saïdi et al, 2012; Marzougui & Oueslati 2017). The initial set of breakwaters that were built in 1989 and 1990 for coastal protection have been replaced by a coastal groins-system in 2018 for further protection (see figure 16). This changed coastal flow and sediment transport dynamics with distinct effects on coastal erosion processes at the Soliman beach.

Figure 15: Geographical location of Soliman beach, Tunisia

Source: Authors.

Figure 16: Changes in the coastal protection of Soliman beach, Tunisia

Breakwaters (1990 – 2018)

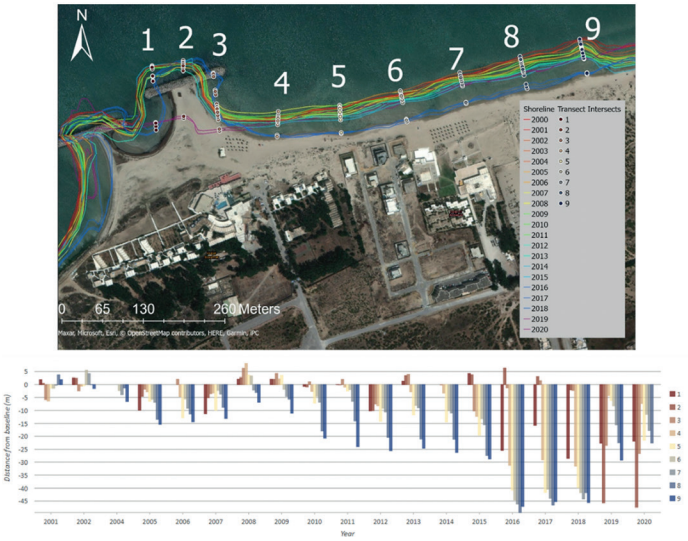
Groin system (2018 – Current)

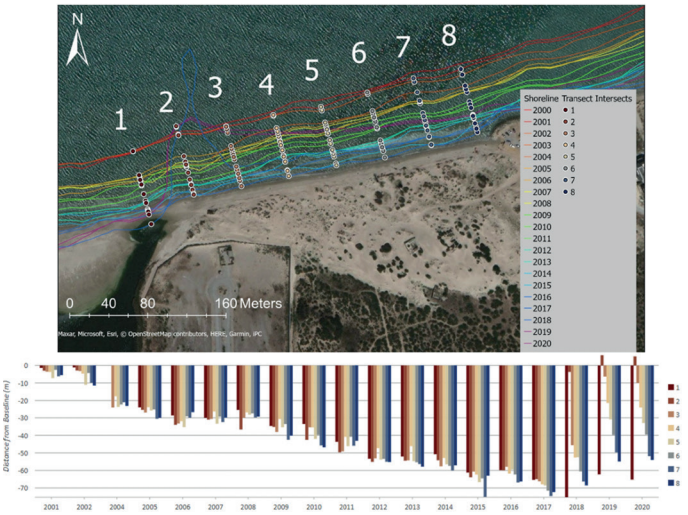
Different protective measures at Soliman beach came with significantly different patterns of coastal erosion over time.

The coastal breakwaters were replaced by a set of coastal groins late 2018. Considering the area where the two breakwaters were replaced in the lower left corner of Soliman beach, the upper panel of Figure 17 below reveals the shoreline changes of this particular area in more detail. The upper part of the figure shows the coastline as of May 2017, i.e. before the replacement of the breakwaters, overlaid with the position of the shoreline in the last two decades, indicated by the differently colored lines. The lower parts then shows the erosion/accretion patterns for each of the transects which are located at different parts of the coast as marked in the upper parts of Figure 17 below. As can be seen from the bar chart in the lower part, especially transect 5 to 9 experienced severe erosion over the years up to 2018. Following the replacement of the breakwaters in 2018, transect 2 shows severe erosion which reflects the removal of the structures. What is more interesting are the changes in transects 5 to 9 in which an immediate and large reversal of the erosion that has been occurring in the years before the introduction of the groins. A similar picture emerges for a part of the shoreline further downstream (lower panel of Figure 17), where the construction of groins (in transect 2) also substantially reduced erosion patterns and led to accretion in the affected areas in the years 2018 to 2020, especially so in transects upstream relative to the structure (i.e. transects 3-8).

The case study also highlights the importance of the temporal dimension inherent to the issue posed by coastal erosion. Considering that erosive processes may accelerate, decelerate or reverse over time, either through human intervention or by natural forces, regular and detailed evaluations of them is important for policymakers to make informed choices with respect to the implementation of protective measures.

Figure 17: Changes in erosion at Soliman beach after replacing breakwaters with groins





Source: Authors.

Responses to coastal erosion hence require regular and site-specific monitoring and analysis of the coastline, should be tailored to the local specificities and incorporate the claims of all possible stakeholders affected by them.

The example described above demonstrates the developments and regeneration of the Soliman beach following the introduction of the groin system that altered sediment transportation over time. Careful planning is necessary to incorporate possible effects of different structures and select the ones that have the desired effects once implemented. The range of different possible measures (be it hard defense solutions like groins, soft solutions such as beach nourishment or nature-based solution, e.g. the re- or afforestation of marsh or mangroves) should be considered. Simultaneously, the possible spillover effects of measures on other parts of the coastline necessitate the incorporation of the various stakeholders along the coast in the planning process in an integrated manner. Hence, a pre-evaluation of adaptation policies should include feasibility and environmental impact assessments in an Integrated Coastal Zone Management (ICZM) process to minimize adverse side-effects of them, as in some instances poorly informed adaptation measures may cause more damage than 'doing nothing' (Hoggart et al, 2014).

Conclusion and further research avenues

The coasts of Maghreb countries are home to large portions of their populations and the economy of them is heavily dependent on their coasts for value creation in several industries. This study presented an assessment of the costs of inaction stemming from the erosion of these coasts. Focusing on the costs of lost land and destroyed built assets, it reveals that such costs are substantial already now for Maghreb countries. We estimate that, even when only considering direct costs, annual losses range from 0.2% of GDP in Algeria to almost 3% of GDP in Tunisia.

While these estimates are an important starting point for the quantification of the costs that arise due to coastal erosion, they neglect costs with regard to economic flows. However, these indirect costs are crucial for the assessment of the overall costs that national and local economics face when confronted with retreating shorelines. To accurately capture them, further research, specifically specifically tailored to the Maghreb countries, is desirable. Possible research avenues include surveys about the willingness to return of tourists given disappearing or substantially reduced beaches, detailed assessments of efficiency losses in coastal infrastructure (such as ports) or the evaluation of the willingness to pay for protective infrastructure (by residents and local businesses but also tourists). Identifying localities where indirect and direct costs due coastal erosion are highest combined with hotspots thereof is imperative in order to assist policy-makers to make informed decisions that yield a favorable cost-benefit ratio. This is particularly important in light of constrained budgets that governments might be willing to set aside for coastal protection.

In order to accurately identify coastal erosion hotspots, the report introduced a novel, fine-scale dataset currently available for Morocco and Tunisia. Created in a cooperation with the National Oceanography Centre of the United Kingdom, it uses satellite imagery with higher resolution than previous global studies of the world's coastlines and refined workflows to enhance accuracy, allowing for more precise assessments of the current state of the coastlines. Making use of historical information about coastal changes enables researchers to make predictions with regards to the future of coasts for policy-relevant timeframes. Furthermore, past interventions for coastal protection can be assessed more accurately as demonstrated with examples from Tunisia.

The extension of this novel dataset to other Maghreb countries is underway and presents a valuable starting point to tackle the negative consequences of coastal erosion where it occurs. However, to further enhance the assessment coastal dynamics and improve forecasting accuracy, additional studies are desirable. These include sediment budgets and flow analyses as well as studies on wave dynamics and geomorphological characteristics for hotspots of coastal erosion but preferably also on a large scale. Understanding these different dynamics is crucial to formulate suitable policy responses to coastal erosion. Furthermore, the insights gained by these studies are important prerequisites for an integrative approach towards coastal development, ideally under the tenants of an Integrated Coastal Zone Management scheme.

The work presented in this report is in close conjunction with a soon to be published flagship report titled "Blue Skies, Blue Seas" that analyzes three of the most pressing environmental issues in MENA, among them coastal erosion. It presents a wide range of possible approaches that can be adopted to protect MENA's and hence the Maghreb's coasts, drawn from regional and international experience. It also complements the efforts of the broader MENA Blue Economy ASA, and additional activities financed by the Korean Green Growth Trust Fund, by providing new insights into the process and the costs of coastal erosion. It thereby contributes to the formulation of appropriate and integrative policy responses to the threat coastal erosion poses for countries in the region.

References

Abdel-Latif, Tarek, Salwa T. Ramadan, and Abeer M. Galal. 2012. Egyptian coastal regions development through economic diversity for its coastal cities. HBRC Journal. Volume 8(3), pp 252-262.

Abou-Dagher, M., M. Nader, and S. El Indary. 2012. Evolution of the Coast of North Lebanon from 1962-2007; Mapping changes for the identification of hotspots and for future management interventions. In: IV International Symposium "Monitoring of Mediterranean Coastal Areas": Problems and Measurement Techniques, Istituto di Biometeorologia (IBIMET), Consiglio Nazionale delle Ricerche (CNR), Italy.

AFED. 2009. Impact of climate change: Vulnerability and adaptation. In: Arab Environment Climate Change. Arab Forum for Environment and Development.

Ahizoun, Mohamed, Eric Maire, Souad Haida, José Darrozes, and J. Probst. 2009. Estimation des changements de la ligne de rivage de la zone côtière sablonneuse de Kénitra au Maroc. Afrique Science: Revue Internationale des Sciences et Technologie. Volume 5(2).

Aitali, Rajaa, Maria Snoussi, and Siham Kasmi. 2020. Coastal development and risks of flooding in Morocco: the cases of Tahaddart and Saidia coasts. Journal of African Earth Sciences. Volume 164, pp 103771.

Alexandrakis, George, Constantine Manasakis, and Nikolaos A. Kampanis. 2015. Valuating the effects of beach erosion to tourism revenue. A management perspective. Ocean & Coastal Management. Volume 111, pp 1-11.

Alonso, I., J. Alcántara-Carrió, and L. Cabrera. 2002. Tourist resorts and their impact on beach erosion at Sotavento beaches, Fuerteventura, Spain. Journal of Coastal Research. Volume 36, pp 1-7.

Amrouni, Oula, Abderraouf Hzami, and Essam Heggy. 2019. Photogrammetric assessment of shoreline retreat in North Africa: anthropogenic and natural drivers. ISPRS Journal of Photogrammetry and Remote Sensing. Volume 157, pp 73-92.

Anfuso, G., E. Pranzini, and G. Vitale. 2011. An integrated approach to coastal erosion problems in northern Tuscany (Italy): Littoral morphological evolution and cell distribution. Geomorphology. Volume 129(3-4), pp 204-214.

Benkhattab, Fatima Zahra, Mounir Hakkou, Ingrida Bagdanavičiūtė, Abdelmounim El Mrini, Hafid Zagaoui, Hassan Rhinane, and Mehdi Maanan. 2020. Spatial–temporal analysis of the shoreline change rate using automatic computation and geospatial tools along the Tetouan coast in Morocco. Natural Hazards. Volume 104(1), pp 519-536.

Bitan, Menashi, and Dov Zviely. 2019. Lost value assessment of bathing beaches due to sea level rise: a case study of the Mediterranean coast of Israel. Journal of Coastal Conservation. Volume 23(4), pp 773-783.

Bouhmadouche, Mohamed, and Yacine Hemdane. 2016 Erosion of a sandy coast: continuous follow-up of the coastal groynes of protection in Boumerdes (Algeria). Environmental Earth Sciences. Volume 75(10).

Carboni, Michele, Carlo Perelli, and Giovanni Sistu. 2014. Is Islamic tourism a viable option for Tunisian tourism? Insights from Djerba. Tourism Management Perspectives. Volume 11, pp 1-9.

Chekirbane, Anis, Maki Tsujimura, Atsushi Kawachi, Hiroko Isoda, Jamila Tarhouni, and Abdallah Benalaya. 2013. Hydrogeochemistry and groundwater salinization in an ephemeral coastal flood plain: Cap Bon, Tunisia. Hydrological Sciences Journal. Volume 58(5), pp 1097-1110.

Cooper, J. Andrew G., Andrew N. Green, and Carlos Loureiro. 2018. Geological constraints on mesoscale coastal barrier behaviour. Global and Planetary Change. Volume 168, pp 15-34.

Croitoru, Lelia, Juan José Miranda, and Maria Sarraf. 2019. The cost of coastal zone degradation in west Africa: Benin, Cote d'ivoire, Senegal and Togo. World Bank.

Dabbeek, Jamal, and Vitor Silva. 2020. Modeling the residential building stock in the Middle East for multi-hazard risk assessment. Natural Hazards. Volume 100(2), pp 781-810.

Darwin, Roy F., and Richard SJ Tol. 2001. Estimates of the economic effects of sea level rise. Environmental and Resource Economics. Volume 19(2), pp 113-129.

Dribek, Abderraouf, and Louinord Voltaire. 2017. Contingent valuation analysis of willingness to pay for beach erosion control through the stabiplage technique: A study in Djerba (Tunisia). Marine Policy. Volume 86, pp 17-23.

El Mrini A. 2011. Évolution morphodynamique et impact des aménagementssur le littoral Tétounais entre Ras Mazari et Fnideq (Maroc nordoccidental). Thèse de 3ème cycle, Univ. Abdelmalek Essadi(Maroc) & Univ. de Nantes (France).

El-Raey, Mohamed. 2010. Impacts and implications of climate change for the coastal zones of Egypt. Coastal zones and climate change. Pp 31-49.

Enríquez, Alejandra R., and Angel Bujosa Bestard. 2020. Measuring the economic impact of climate-induced environmental changes on sun-and-beach tourism. Climatic Change. pp 1-15.

Flayou, Latifa, Maria Snoussi, Raji Otmane, and Otmane Khalfaoui. 2017. Valuing the Economic Costs of Beach Erosion Related to the Loss in the Tourism Industry: The Case of Tetouan Coast (Morocco). In: Euro-Mediterranean Conference for Environmental Integration, pp. 1633-1636. Springer, Cham.

Fraser, Rob, and Geoff Spencer. 1998. The value of an ocean view: an example of hedonic property amenity valuation. Australian Geographical Studies. Volume 36(1), pp 94-98.

Ghermandi, Andrea, and Paulo ALD Nunes. 2013. A global map of coastal recreation values: Results from a spatially explicit meta-analysis. Ecological economics. Volume 86, pp 1-15.

Gray, John S. 1997. Marine biodiversity: patterns, threats and conservation needs. Biodiversity & Conservation. Volume 6(1), pp 153-175.

Hamilton, Jacqueline M. 2007. Coastal landscape and the hedonic price of accommodation. Ecological Economics. Volume 62(3-4), pp 594-602.

Hayes, Miles O., and Duncan M. FitzGerald. 2013. Origin, evolution, and classification of tidal inlets. Journal of Coastal Research. Volume 69, pp 14-33.

Hoggart, S. P. G., M. E. Hanley, Dennis J. Parker, D. J. Simmonds, D. T. Bilton, M. Filipova-Marinova, E. L. Franklin, I. Kotsev, E.C. Penning-Rowsell, S.D. Rundle, E. Trifonova, S. Vergiev, A.C. Whie and R.C. Thompson. 2014. The consequences of doing nothing: The effects of seawater flooding on coastal zones. Coastal Engineering. Volume 87, pp 169-182.

Huang J, Parsons GR, Poor PJ, Zhao MQ. 2011. Combined conjoint-travel cost demand model for measuring the impact of erosion and erosion control programs on beach recreation. In: Preference Data for Environmental Valuation: Combining Revealed and Stated Approaches, ed. T Haab, J Huang, J Whitehead, pp. 115–38. New York: Routledge.

Jeffrey, H. and Bleasdale, S. 2017. Tunisia: MassTourism in Crisis? In: Mass Tourism in a Small World. CAB International, pp 191-199. Kasmi, Siham, Maria Snoussi, Otmane Khalfaoui, Rajaa Aitali, and Latifa Flayou. 2020. Increasing pressures, eroding beaches and climate change in Morocco. Journal of African Earth Sciences. Volume 164, pp 103796.

Laffoley, Dan, and Gabriel D. Grimsditch. 2009. The management of natural coastal carbon sinks. IUCN, Gland.

Landry, Craig E., Andrew G. Keeler, and Warren Kriesel. 2003. An economic evaluation of beach erosion management alternatives. Marine Resource Economics. Volume 18(2), pp 105-127.

Landry, Craig E., and Haiyong Liu. 2009. A semi-parametric estimator for revealed and stated preference data—An application to recreational beach visitation. Journal of Environmental Economics and Management. Volume 57(2), pp 205-218.

Landry, Craig E., and Haiyong Liu. 2011. Econometric models for joint estimation of revealed and stated preference site-frequency recreation demand models. In: Preference Data for Environmental Valuation: Combining Revealed and Stated Approaches, ed. T Haab, J Huang, J Whitehead, pp. 115–38. New York: Routledge.

Luijendijk, Arjen, Gerben Hagenaars, Roshanka Ranasinghe, Fedor Baart, Gennadii Donchyts, and Stefan Aarninkhof. 2018. The state of the world's beaches. Scientific reports. Volume 8(1), pp 1-11.

Martínez, Maria Luiza, A. Intralawan, G. Vázquez, O. Pérez-Maqueo, P. Sutton, and R. Landgrave. 2007. The coasts of our world: Ecological, economic and social importance. Ecological economics. Volume 63(2-3), pp 254-272.

Marzougui, Wissem, and Ameur Oueslati. 2017. Les plages de la côte d'Ejjehmi-Soliman (golfe de Tunis, Tunisie): exemple d'accélération de l'érosion marine dans une cellule sédimentaire artificiellement tronçonnée. Physio-Géo. Géographie physique et environnement. Volume 11, pp 21-41.

Maul George A., and Iver W. Duedall. 2019. Demography of coastal populations. In: Encyclopedia of coastal science 2nd edition, pp 692-699. Cham: Springer.

Mentaschi, Lorenzo, Michalis I. Vousdoukas, Jean-Francois Pekel, Evangelos Voukouvalas, and Luc Feyen. 2018 Global long-term observations of coastal erosion and accretion. Scientific reports. Volume 8(1), pp 1-11.

Nader, Manal. 2015. Presentation: Coastal zone management in Lebanon. https://www.pseau.org/outils/ouvrages/uob_coastal_zone_management_in_lebanon_2015.pdf, accessed Jan 18, 2021.

Nicholls, RJ, Wong, PP, Burkett, VR, Codignotto, J, Hay, J, McLean, R, Ragoonaden, S, and Woodroffe, CD. 2007. Coastal systems and low-lying areas. In: Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press. pp 315-356.

NOC. 2020. Using optical satellite shoreline detection to measure historic and forecast future sandy shoreline changes in North Africa. National Oceanographic Center, Technical Report.

OECD-FAO. 2018. The Middle East and North Africa: Prospects and challenges. In: OECD-FAO Agricultural Outlook 2018-2027. Organisation for Economic Co-operation and Development / Food and Agriculture Organization.

Oueslati, Ameur, Omar Labidi and Tharouet Elamri. 2015. Atlas de la vulnérabilité du littoral tunisien à l'èlèvation du niveau marin. United Nation Development Program.

Pardo-Pascual, Josep E., Elena Sánchez-García, Jaime Almonacid-Caballer, Jesús M. Palomar-Vázquez, Enrique Priego De Los Santos, Alfonso Fernández-Sarría, and Ángel Balaguer-Beser. 2018. Assessing the accuracy of automatically extracted shorelines on microtidal beaches from Landsat 7, Landsat 8 and Sentinel-2 imagery. Remote Sensing. Volume 10(2), 326.

Parsons, George R., and D. Matthew Massey. 2003. A random utility model of beach recreation. The new economics of outdoor recreation. pp 241-267.

Parsons, George R., Zhe Chen, Michael K. Hidrue, Naomi Standing, and Jonathan Lilley. 2013. Valuing beach width for recreational use: combining revealed and stated preference data. Marine Resource Economics. Volume 28(3), pp 221-241.

Pendleton, Linwood, Craig Mohn, Ryan K. Vaughn, Philip King, and James G. Zoulas. 2012. Size matters: the economic value of beach erosion and nourishment in Southern California. Contemporary Economic Policy. Volume 30(2), pp 223-237.

Pompe, Jeffrey J., and James R. Rinehart. 1995. Beach quality and the enhancement of recreational property values. Journal of Leisure Research. Volume 27(2), pp 143-154.

Raybould, Mike, David Anning, Dan Ware, and Neil Lazarow. 2013. Beach and surf tourism and recreation in Australia: Vulnerability and adaptation. Gold coast: Bond University.

Rigall-I-Torrent, Ricard, Modest Fluvià, Ramon Ballester, Albert Saló, Eduard Ariza, and Josep-Maria Espinet. 2011. The effects of beach characteristics and location with respect to hotel prices. Tourism Management. Volume 32(5), pp 1150-1158.

Rinehart, James R., and Jeffrey J. Pompe. 1994. Adjusting the market value of coastal property for beach quality. The Appraisal Journal. Volume 62(4), pp 604-608.

Sahr, Kevin, Denis White, and A. Jon Kimerling. 2003. Geodesic discrete global grid systems. Cartography and Geographic Information Science. Volume 30(2), pp 121-134.

Saïdi, Hanen, Radhia Souissi, and Fouad Zargouni. 2012. Environmental impact of detached breakwaters on the Mediterranean coastline of Soliman (North-East of Tunisia). Rendiconti Lincei. Volume 23(4), pp 339-347.

Schäfer, Katja. 2013. Urbanization and urban risks in the Arab region. Presentation at: First Arab region conference for disaster risk reduction. United Nations Habitat.

Schuhmann, Peter W., Brittany E. Bass, James F. Casey, and David A. Gill. 2016. Visitor preferences and willingness to pay for coastal attributes in Barbados. Ocean & coastal management. Volume 134, pp 240-250.

Scott, Daniel, Murray Charles Simpson, and Ryan Sim. 2012. The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise. Journal of Sustainable Tourism. Volume 20(6), pp 883-898.

Sharaan, Mahmoud, Chatuphorn Somphog, and Keiko Udo. 2020. Impact of SLR on Beach-Tourism Resort Revenue at Sahl Hasheesh and Makadi Bay, Red Sea, Egypt; A Hedonic Pricing Approach. Journal of Marine Science and Engineering. Volume 8(6), pp 1-13.

Sieghart, Lia Carol, Joseph Allen Mizener, and Jeff Gibson. 2019. Capturing Opportunities for Integrated Coastal Zone Management and the Blue Economy in MENA. MENA knowledge and learning: Quick notes series. Number 172. The World Bank.

Small, Christopher, and Robert J. Nicholls. 2003. A global analysis of human settlement in coastal zones. Journal of coastal research. Volume 19(3), pp 584-599.

Snoussi, Maria, Otmane Khalfaoui, Latifa Flayou, Siham Kasmi, and Otmane Raji. 2017. Can ICZM Help the Resilience of Disappearing Beaches in the Face of Climate Change? In: Euro-Mediterranean Conference for Environmental Integration. pp. 29-30. Springer, Cham.

Snoussi, Maria, Tachfine Ouchani, Abdou Khouakhi, and Isabelle Niang-Diop. 2009. Impacts of sea-level rise on the Moroccan coastal zone: quantifying coastal erosion and flooding in the Tangier Bay. Geomorphology. Volume 107(1-2), pp 32-40.

Snoussi, Maria, Tachfine Ouchani, and Saïda Niazi. 2008. Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: the case of the Mediterranean eastern zone. Estuarine, Coastal and Shelf Science. Volume 77(2), pp 206-213.

Sytnik, Oxana, Laura Del Río, Nicolas Greggio, and Jarbas Bonetti. 2018. Historical shoreline trend analysis and drivers of coastal change along the Ravenna coast, NE Adriatic. Environmental Earth Sciences. Volume 77(23), pp 1-20.

Tarui, Nori, Marcus Peng, and Dolan Eversole. 2018. Economic Impact Analysis of the Potential Erosion of Waikīkī Beach. University of Hawai'i Sea Grant College Program. Honolulu: University of Hawai' i at Mānoa.

Trakadas, Athena. 2020. Natural and anthropogenic factors impacting northern Morocco's coastal archaeological heritage: A preliminary assessment. The Journal of Island and Coastal Archaeology. 1-32.

Uyarra, Maria C., Isabelle M. Cote, Jennifer A. Gill, Rob RT Tinch, David Viner, and Andrew R. Watkinson. 2005. Island-specific preferences of tourists for environmental features: implications of climate change for tourism-dependent states. Environmental conservation. Volume 32(1), pp 11-19.

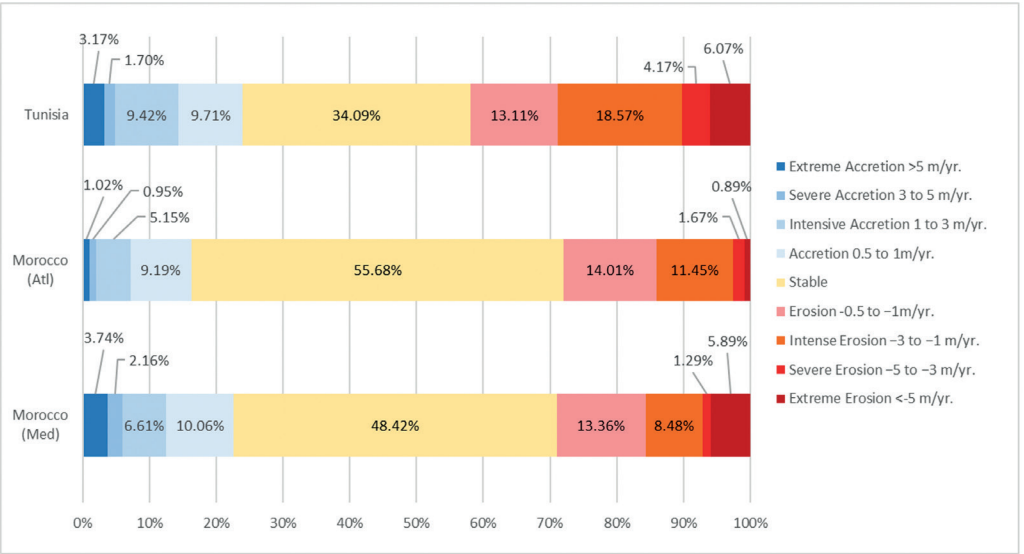
Widz, Monika, and Teresa Brzezińska-Wójcik. 2020. Assessment of the Overtourism Phenomenon Risk in Tunisia in Relation to the Tourism Area Life Cycle Concept. Sustainability. Volume 12(5), pp 1-13.

Whitehead, John C., Christopher F. Dumas, Jim Herstine, Jeffery Hill, and Bob Buerger. 2008. Valuing beach access and width with revealed and stated preference data. Marine Resource Economics. Volume 23(2), pp 119-135.

Whitehead, John C., Daniel J. Phaneuf, Christopher F. Dumas, Jim Herstine, Jeffery Hill, and Bob Buerger. 2010. Convergent validity of revealed and stated recreation behavior with quality change: a comparison of multiple and single site demands. Environmental and Resource Economics. Volume 45(1), pp 91-112.

Appendix

Figure A1: Shoreline changes within Tunisia and Morocco according to Luijendijk et al (2018)



Source: Authors based on Luijendijk (2018)

Maghreb Department,
Middle-East and North Africa Region

www.worldbank.org