



## Impacts of Sea Level Rise on the Marchica Lagoon in the North-East of the Moroccan Mediterranean Coast

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### ABSTRACT

Marchica Lagoon is a vulnerable coastal area of Morocco that is undergoing rapid socio-economic changes. It is also one of the most important lagoons in the Mediterranean region, providing vital economic, biological, ecological, and touristic benefits to eastern Morocco. The lagoon is highly vulnerable to sea level rise (SLR), which is exacerbated by the loss of natural coastal defences, such as dune barriers, and high urbanization. The present work aimed to investigate the potential impacts of sea level rise and analyze the vulnerability of the Marchica Lagoon to simulated submersion based on possible scenarios. To achieve the current goals, we relied on the elevation data obtained from the 2018 aerial rendition, while details on elevation points in the study area were collected and extracted using aerial imagery and the digital elevation model (DEM) database from 2023. With the use of GIS simulation technology to estimate areas at risk of submersion, DEM and sea level were linked using GIS simulation technology. Recent research has shown that a 1m rise in sea level would submerge 30% of the dune belt, while a 2m rise would submerge 65% of the dune barrier, as all urban constructions below 2m above sea level would be severely affected. LRT can lead to significant changes in the lagoon ecosystem, having a direct impact on marine wildlife and, consequently, on fishing practices and research. Research has revealed that current and planned developments around the lagoon are located in highly vulnerable areas, and that the impacts of sea level rise will be exacerbated by other impactsfacteurs, such as population growth, urbanization and climate change. Therefore, in order to mitigate the effects of sea level rise on the Marchica Lagoon, it is necessary to develop response methods to identify the most appropriate adaptation solutions.

### INTRODUCTION

Sea level rise, linked to climate change, is currently a major concern for governments, organizations, research centers and scientific studies due to its implications and risks to coastal areas. The increase in soil temperature from 2 to 3°C will, under some hypothetical scenarios, result in the loss of more than 50% of the average coastal areas (Bahkan *et al.*, 2018) due to rising sea levels and increases in marine storms and hurricanes. Some studies confirm that the average global warming over the past 100 years

has been 0.74 degrees Celsius, and that the last 10 years have been the warmest (ACCMA, 2010). Thus, since the end of the nineteenth century, the global average temperature has increased by 1.1°C (Climate.copernicus.eu, 2018) and according to the IPCC (Intergovernmental Panel on Climate Change), this warming could further accelerate to reach +1.5 to +6°C by the end of the century. The Earth's temperature is therefore likely to increase as much in 200 years as it has in the last 22,000 years. Increasing global warming is expected to lead to heavy losses, especially for coastal dwellers, deltas and lagoons due to rising sea levels and worsening marine storms and hurricanes.

Marchica Lagoon is a semi-enclosed lagoon located on the northeastern coast of the Moroccan Mediterranean. It is separated from the Mediterranean Sea by a dune barrier that plays a vital role in protecting the lagoon from coastal hazards such as storm surges and flooding. However, the dune barrier is vulnerable to sea level rise, which is expected to accelerate in the coming decades due to climate change.

Several studies have assessed the vulnerability of the Marchica Lagoon to sea level rise. A study by Hlal *et al.* (2023) found that the entire dune barrier is at risk of flooding under a one-metre sea-level rise scenario. The study also showed that the most vulnerable areas are the northern and southern ends of the dune belt.

The problem of sea level rise is not yet widely debated, but some scientific facts obtained by some institutes indicate that the level of the Mediterranean has risen by 2.5mm/ year since 1990. Within 50 years, this level could reach 50 centimetres (Bahkan *et al.*, 2018) and double by the end of the century. This means that a large part of the study area, which includes many economic and tourist bets, as well as many sites of economic importance such as small-scale fishing complexes, will be submerged.

The studies published by Haddouti *et al.* (2016) and by Bahkan *et al.* (2018) showed that sea-level rise is likely to have a significant impact on the ecosystems, economy and infrastructure of the Marchica Lagoon. The study identified a number of potential impacts, including: (i) increased flooding and erosion of the dune barrier, (ii) loss of coastal wetlands and damage to coastal infrastructure, such as roads, buildings, and ports, (iii) salinization of freshwater resources, and (iv) disruption of economic activities, such as tourism and fishing.

Other studies confirm the Marchica Lagoon's high vulnerability to sea level rise, impacting ecosystems, economy, and infrastructure. Adaptation measures are crucial for mitigation and community protection.

In addition, the expected rise in sea level will have a serious impact on Morocco's coastal areas, where 80% of the country's industrial and energy infrastructure is located, as well as the densest communication networks, the highest population densities and the most fertile agricultural plains, where most of the country's economic activities are concentrated, including agriculture, fisheries and aquaculture, trade, tourism, and among others (CNI, 2001).

The main objective of our study on the consequences of sea level rise in the Marchica Lagoon was to focus particularly on its impact on fishing activity. The analysis aimed to focus on the specific impacts of this elevation on the fishing practices, target species, and livelihoods of the communities that depend on this activity. In addition, we sought to formulate management measures to reduce the effect of the risks of marine submersion and to regulate the land use pattern around the Marchica Lagoon.

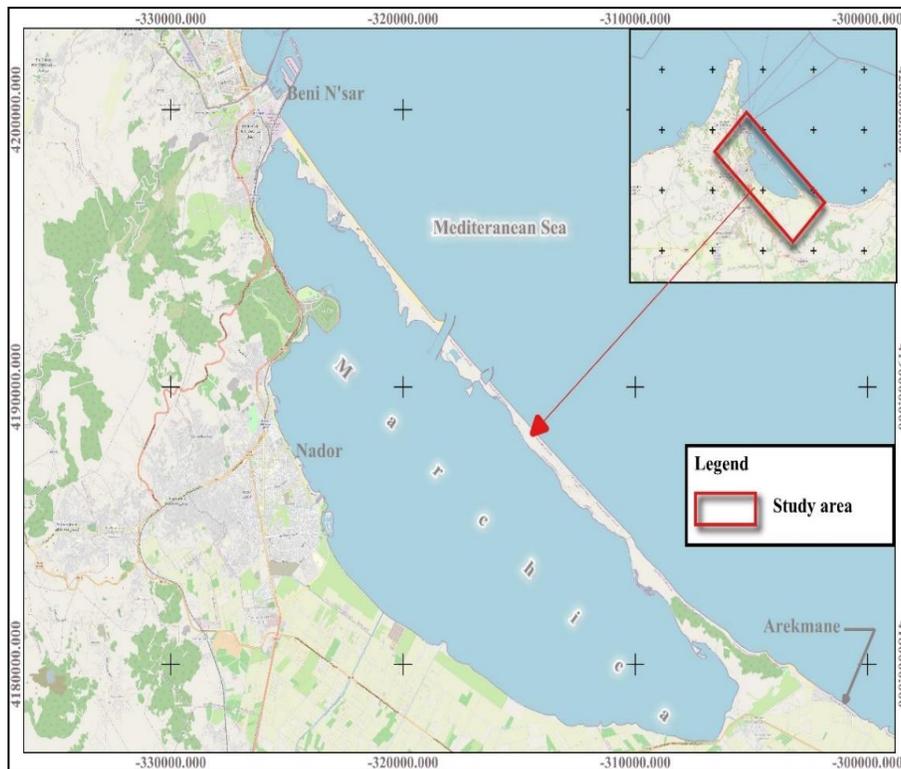
## MATERIALS AND METHODS

### Study area

The Marchica Lagoon, classified as a Site of Biological and Ecological Interest (SIBE) and Ramsar (Convention on Wetlands) site since 2005, is one of the most important lagoons and the second largest in the Mediterranean. It is semi-elliptical in shape and separated from the Mediterranean Sea by a dune belt. A natural channel connects the lagoon to the sea (Fig. 1). The lagoon is home to a wide variety of flora and fauna habitats, serving as resting, nesting, and wintering area for birds of global interest, and harboring important fish resources (**Haddouti *et al.*, 2016**). The lagoon is of a vital economic, biological, ecological and tourist importance for the eastern region of Morocco, in particular the province of Nador (**Agency for the Development of the Marchica Lagoon Site, 2015**)

Marchica Lagoon is located on the northeastern coast of the Moroccan Mediterranean between Cap des Trois Fourches and Cap de l'Eau. It occupies a 25km long coastal strip corresponding to the central part of Nador Bay. The lagoon runs parallel to the coast, with an area of 115km<sup>2</sup> and an average depth of 8m (**Niazi *et al.*, 2006**).

Thanks to its geomorphological structure characterized by ease of access, proximity to seaside resorts and proximity to the urban environment (**Izri *et al.*, 2002**), the Marchica Lagoon is a major element in the development of tourism.



**Fig. 1.** Location of Marchica on the Mediterranean coast of Morocco (**Open Street Map, 2023**)

The mapping approach was adopted to study the impact of sea level rise on the field studied, following the following steps:

### **Data collection and processing**

Elevation data were extracted from the 2018 aerial report, and information on elevation points in the study area was collected and extracted using aerial imagery and the digital elevation model (DEM) database (2023). The DEM was produced based on a third irregular network (TIN) and a database of GPS-measured ground control points, allowing for an accurate and correct representation of all fine models, such as roads, dunes, and buildings (2023).

### **Data analysis and visualization of results**

Geographic information system (GIS) simulation technology was used to link the DEM and sea level, assuming a height of 1m, to estimate the flood risk area. The results of the mapping of areas at risk of marine submersion according to the scenarios (0.5, 1.5, and >1.5m) were used to propose adaptation options to be implemented in response to this phenomenon in the coming years.

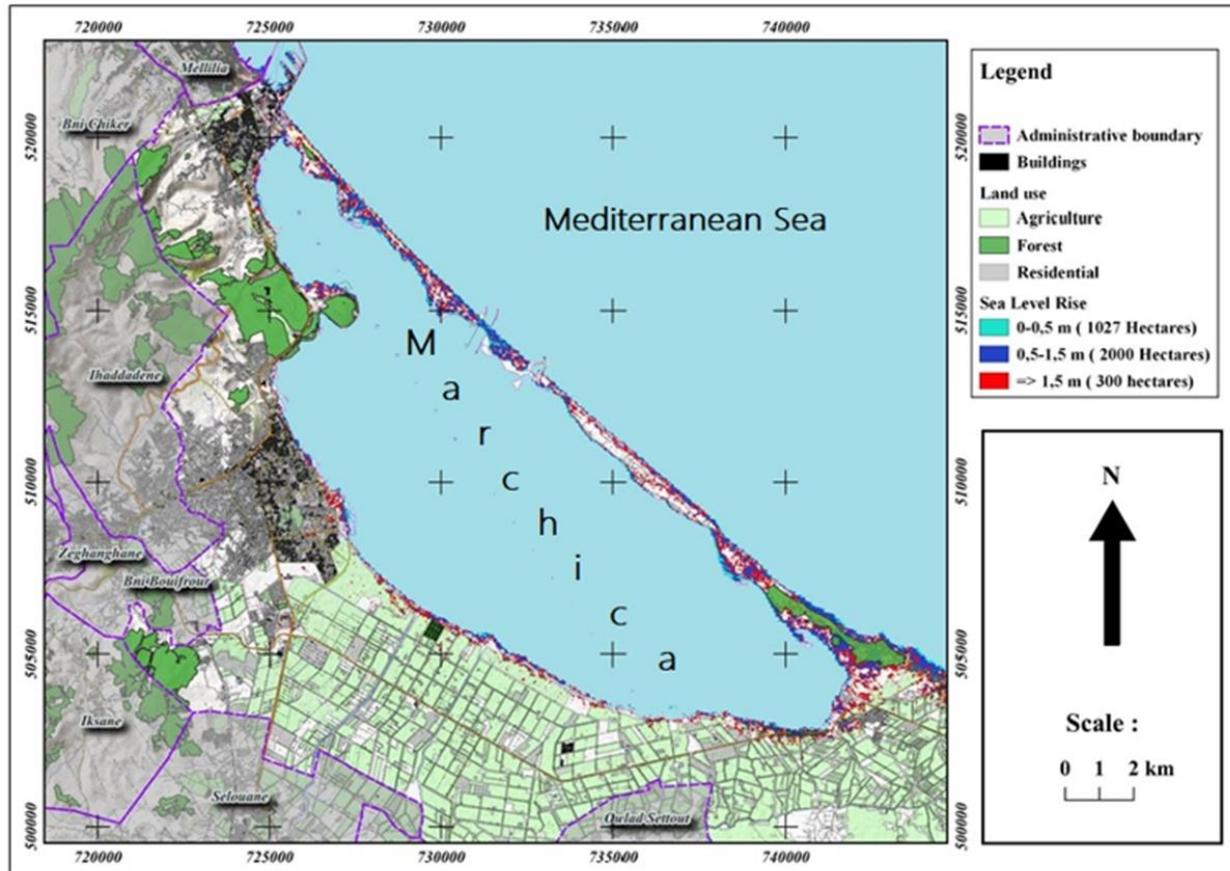
This combined paragraph is more concise and easier to read since it moves logically from one step to the next. It also avoids the repetition of information, such as mention of DEM and GIS technology. In addition, the combined paragraph highlights the main objective of the study, which was to propose options for adaptation to sea-level rise.

Submergence impacts were assessed using digital elevation models (DEMs). These DEMs were created by compiling various topographic data into digital format using ArcGIS software. After identifying the challenges related to sea level rise, we developed a map of the risks of anticipated flooding and analyzed the possible impacts of this phenomenon.

## **RESULTS AND DISCUSSION**

The dune barrier is the first line of defence against coastal flooding. However, due to its low elevation, it is particularly vulnerable to sea level rise. The mapping results show that even a modest sea level rise (1 to 1.5m) would submerge the entire dune belt, with the exception of a small protected part at Al Mouhandis.

The northwestern part of the spit and Arekmane are also highly vulnerable to sea level rise. These areas are already experiencing flooding during high tides and storm surges. As sea levels rise, these areas are at risk of being permanently submerged, resulting in the loss of critical infrastructure, such as roads, buildings, and farmland (Fig. 2).



**Fig. 2.** Marine submersion risk zone scenario

The Marchica Lagoon is an ecologically fragile ecosystem due to natural factors and human interventions. It is important to resist these imbalances, especially in light of the large-scale and high-cost development projects planned in the region. The sustainability of these projects needs to be assessed in the context of sea-level rise.

The areas surrounding the Marchica Lagoon are experiencing a significant increase in the socio-economic vulnerability index, due to the increase in population density. This is particularly evident in Bouaruoro District, Ishumay District of Nador, and Central Arekmane District, where many facilities are concentrated. Any rise in sea level would be dangerous in this region, where tourism projects with lakeside terraces are most threatened. Then, there are the disproportionate environmental risks linked to climatic hazards, particularly in the peripheral districts near the areas of the Gourougou mountains and the Kbdanna ranges where rainfall sometimes reaches critical thresholds of 400mm.

The vulnerability of the study area lies in the need to identify development prospects and planning principles for the coastal zone of the Marchica Lagoon, with a view to avoiding flood risks and adverse effects of sea level rise caused by climate change and rising water tables.

While the risk of marine submersion in the coastal areas of Marchica Lagoon is relatively low in the first scenario (0- 0.5m), it increases significantly in the second and third scenarios (0.5- 1.5 and more than 1.5m). Satellite measurements indicate that the eastern Mediterranean region is experiencing a sea-level rise rate of 2mm/ year (**IRES, 2010; Hlal, 2023**). This could have catastrophic effects on Marchica in general, and on the coastal dune barrier in particular since it is a low-lying area where many people live and whose economy is linked to natural resources.

The study area is already experiencing several problems, including numerous floods due to rising water levels in the valleys and increased salinity of the water table. Sea level rise would further exacerbate these problems and also lead to the disappearance of many beaches, such as Taouarirt Beach, Al Mouhandis Beach, Arkmane Beach, Miami Beach, and Boukana Beach in Beni N'sar. It would also have an impact on important forest areas and agricultural land in the Bouareg plain.

The coast of the Marchica Lagoon is characterized by a relatively low dune barrier (0.4m), with the exception of the middle part known as Al Mouhandis.

This is an important factor that increases the risk of marine submersion, as much of the dune barrier forms wetlands at low elevation levels. In addition, a large part of the dune barrier extends into the Bouareg plain region, which is also exposed to the risk of flooding. The danger of marine submersion in these coastal areas lies in the fact that they include several residential communities and infrastructures, more than 19 sites of gathering of fishermen practicing traditional fishing, in addition to tourist sites that have been completed (the city of Atalayoun), are nearing completion (the city of the two seas) or are planned (the Bay of Flamingos and the fishing village).

### **Vulnerability of Marchica Lagoon to accelerated sea level rise**

The vulnerability of coastal areas to natural hazards, and in particular to sea level rise due to global warming, is a major area of research. According to some scenarios (**Lasгаа, 2010; Hlal, 2023**), global warming of 2- 3°C would lead to the loss of more than 50% of the Mediterranean coastal areas due to sea level rise and increased marine storms. Lagoons and deltas are particularly vulnerable

Marchica Lagoon is one of the most vulnerable coastal areas to sea level rise in Morocco. It is characterized by its sparse topography and is experiencing a strong economic (agriculture, fishing, tourism) and demographic (high population density) expansion.

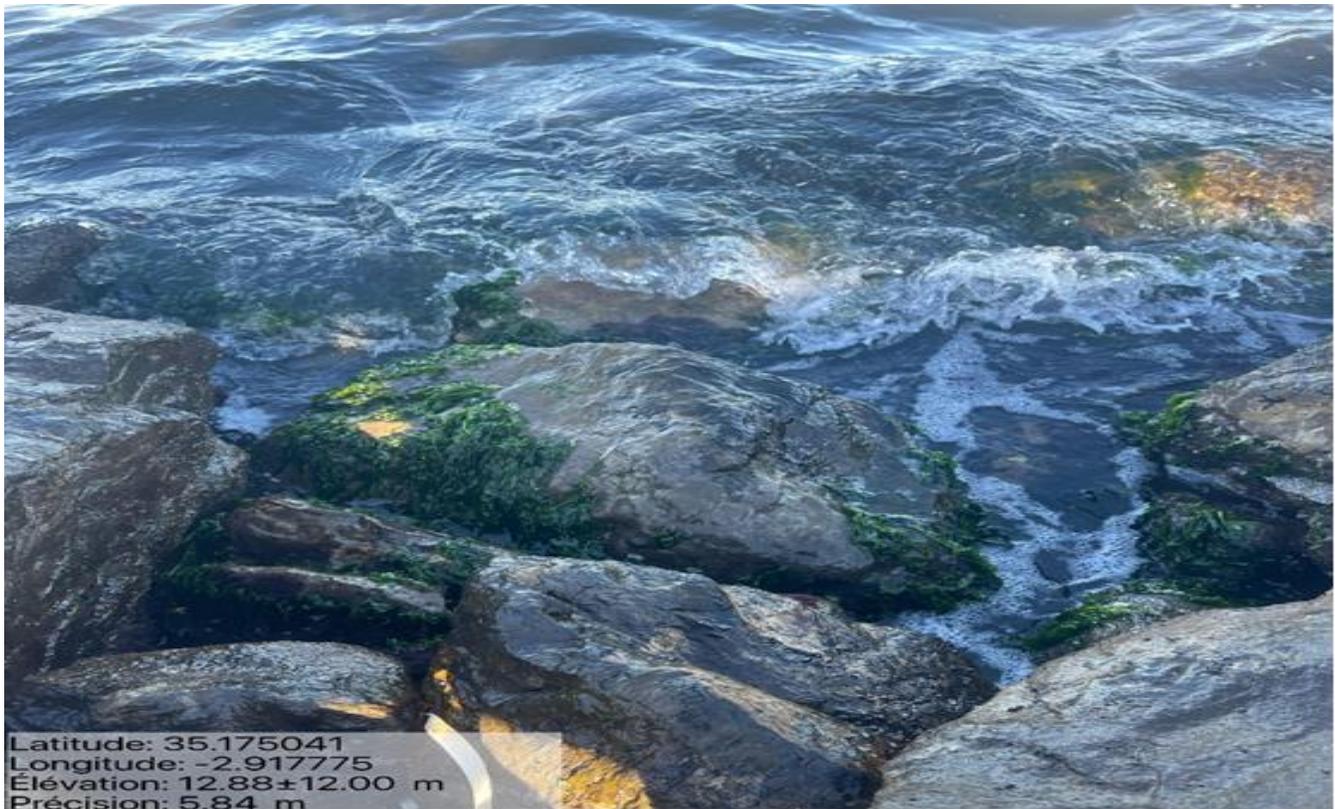
### **Vulnerability of coastal ecosystems to sea-level rise**

The projected sea level rise in the coming decades is expected to have the following consequences on the coasts:

- Permanent submersion of low-lying coastal areas, such as deltaic plains and lagoon margins.

- Maritime marshes and coral reefs.
- Accelerated erosion of cliffs and beaches.
- Increased salinization of estuaries and salt contamination of freshwater aquifers.

In the Marchica Lagoon, the main habitats likely to be affected by sea level rise are eelgrass beds with *Zostera noltii*, *Cymodocea nodosa* and a dense algal mat (*ulvae*), which support many species of molluscs and crustaceans of socio-economic interest (Photo 1).



**Photo 1.** The algae (*ulvae*) of the Marchica lagoon

Eelgrass beds with *Zostera noltii* are the lungs of this lagoon, and home to many species. A rise in sea level would deprive this system of alternating immersion and other elements necessary for its development.

Studies on the effects of sea level rise are primarily based on sea level forecasts. The sea level rise levels used come from the IPCC (Intergovernmental Panel on Climate Change) A2 climate scenario for the years 2050 and 2100. These climate scenarios are projections of future climate change based on greenhouse gas emissions. The study also includes a hypothetical maximum sea level rise of 2 meters, accelerated by waves, by 2100. This suggests that the researchers considered an extreme scenario to assess the potential impacts of sea level rise, taking into account the additional effect of swell. The analysis is therefore based on specific IPCC climate projections, with a particular attention paid to a maximum scenario of sea level rise of 2 meters by 2100, accelerated

by swells. This approach allows for the assessment of potential risks and the planning of adaptation measures accordingly.

**Table 1.** Elevation levels used for forecasting

Temporary horizon	2050	2100	
Level type	Minimum	Medium	Maximum
Value (m)	0.23	0.51	2

### **Projected impacts of Marchica Lagoon on sea Level rise: An environmental and economic problem**

According to an analysis of the effects of sea level rise in the Machic Lagoon, the surrounding ecosystems will suffer major consequences. The sustainability of human activities in the lagoon and biodiversity are both significantly affected by sea level rise, which acts as a catalyst for environmental change.

The first impact of the entry of salt water into the lagoon is a disturbance of the delicate balance of salinity, which has an immediate effect on organisms acclimatized to lagoon water which is saltier than the Mediterranean water. Rising sea levels cause recurrent flooding that accelerates the deterioration of coastal habitats such as wetlands and marshes. Additionally, the formation of *Juncus rigidus*, which is an endemic formation, is endangered. This degradation in turn leads to the loss of critical habitats for many animal and plant species. In summary, the biological balance of the lagoon is threatened by saltwater intrusion, which endangers critical habitats for flora and fauna.

There are noticeable changes in the species composition of the lagoon, which has an impact on its biodiversity. Ecological balances are threatened by the translocation of species caused by changes in salinity and habitat deterioration. The productivity of local fisheries, especially small-scale fisheries, is heavily affected by the loss of crucial breeding and feeding grounds for fish and shellfish.

Beaches and coastal infrastructure are threatened by the growing threat of coastal erosion. The direct threat to human settlements and land highlights the complex issues facing the local community.

The Marchica Lagoon is a delicate environment that is crucial to the biodiversity of the region and serves as a major economic hub for nearby towns. The lagoon and its inhabitants are severely threatened by rapidly rising sea levels. According to the ACCMA report, sea level rise would impact the following economic sectors :

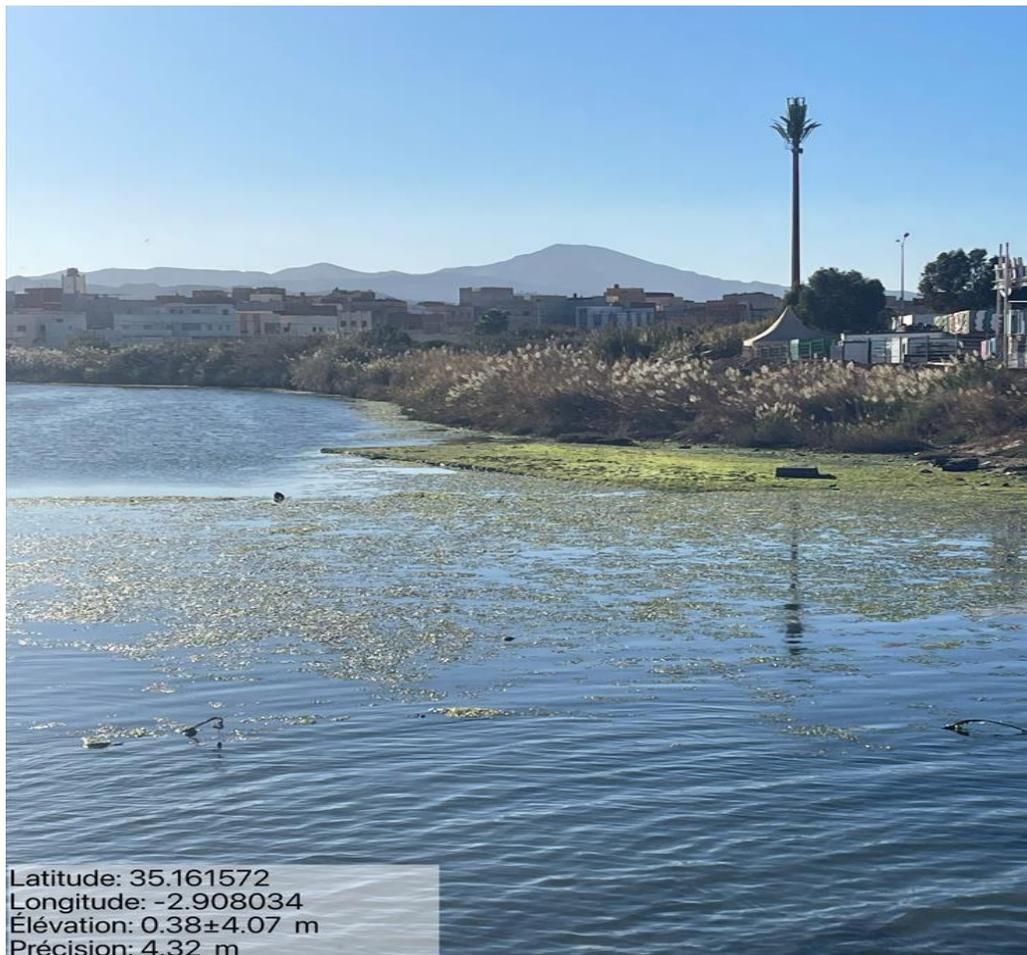
**Tourism:** The Marchica Lagoon is one of the most visited tourist spots. Rising sea levels can have a negative impact on the local economy by causing damage to beaches, accommodation establishments, and recreational areas. 68 hectares of tourist properties would be underwater for a sea level rise of 0.23m, and 124 hectares underwater for a sea level rise of 0.51m.

**Agriculture:** Due to the intrusion of seawater, agricultural land in the vicinity of the lagoon is susceptible to salinization, reducing agricultural production. Crop and income losses could affect the ability of local farmers to sustain themselves. Low-lying agricultural areas would be flooded by projected sea level rise, especially irrigated crops in the Bouareg plain. An elevation of 0.23 metres would mean the loss of 16 hectares of

Bour land and 64 hectares of irrigated land. The losses of Bouareg and irrigated land would be 27 hectares and 112 hectares, respectively, with an elevation of 0.51m.

**Industry:** Near the port of Beni Ensar, in the northern part of the lagoon, there is an industrial zone. It could be affected by a rise in sea level as it covers 60 hectares. 3.3% of this area would be attacked for a 0.23m LRT, and 8.3% of this area would be affected for a 0.51m SLR.

**Small-scale fishing:** The Marchica Lagoon is an important fishing spot. The availability of fisheries resources and the disruption of marine ecosystems caused by sea level rise can impact nearby fishing communities. Loss of vital coastal habitats, including marshes and *Juncus rigidus* formations, can be caused by sea level rise. Many fish species use these areas as breeding and feeding grounds, which can lead to a decrease in available fish stocks. Given the number of jobs it creates, this industry is crucial to the region's food supply and represents a growth opportunity for the 240km of Mediterranean coastline that this district covers. Operating outside the formal circuits, this activity is the main socio-economic enterprise of the Marchica Lagoon. For all three levels of LRS, all traced fishing sites in the lagoon would be vulnerable to submersion.



**Photo 2.** The *Juncus rigidus* formations of the Marchica Lagoon

Sea level rise is having a major impact, especially on small-scale fishing activities, according to research and surveys of fishermen in the Marchica Lagoon.

The anticipated impacts of sea-level rise on small-scale fisheries in the Marchica Lagoon present a series of challenges with significant implications for this vital coastal activity. These challenges include the relocation of fishing grounds due to the changing geography.

The expected rise in sea level could reshape the geography of the lagoon, leading to shifts in traditional fishing grounds. Small-scale fishers may have to adapt to new areas, impacting catch yield and fish species composition. This change poses a significant challenge to the established practices of these fishers, increasing the vulnerability of fishing infrastructure to flooding and erosion; sea-level rise also poses a direct threat to critical fisheries infrastructure, including landing sites and storage facilities. In addition, increased vulnerability to flooding and erosion is likely to disrupt daily fishing operations and affect the storage and processing of catches. The resilience of fisheries infrastructure is becoming essential to ensure the continuity of small-scale fishing activities.

In addition, changes in coastal habitats induced by sea-level rise can influence the behavior and distribution of fish species. These impacts also lead to socio-economic stress for small-scale fishing communities, which are poised to be put to the test due to disruptions to fishing patterns and infrastructure. These disruptions can impact the incomes, livelihoods, and overall well-being of these communities, highlighting the need for comprehensive resilience-building measures and sustainable practices. Small-scale fishers may be forced to adapt their fishing practices to the changing environmental conditions. This may include modifying fishing gear, adjusting fishing schedules, or exploring innovative techniques to address the challenges posed by changing landscapes.

**Infrastructure:** 1km of main roads and 18km of secondary roads would be affected by a sea level rise of 0.23m. Ports, bridges, and tourist attractions are among the coastal infrastructure that is prone to flooding. A sea level rise of 0.51m would impact 2km of main roads and 29km of secondary roads. Ports, bridges and tourist attractions are part of the coastal infrastructure that is susceptible to flooding and erosion. Rebuilding and maintaining this infrastructure can be costly.

The following other areas may be affected by sea level rise in the Marchica Lagoon:

**Trade and sea level rise:** It can destroy port infrastructure and impede trade.

**Real Estate and coastal properties:** It can lose value due to rising sea levels, making them more difficult to sell or rent. However, on the other hand, elevation can have a favorable and beneficial impact for a significant boom in real estate and tourism activities, as is the case with the Italian city of Venice. This requires a very significant investment to adapt the infrastructure of the city of Nador to a particular situation, such as that of a city located in the water, such as Venice in Italy.

**Utilities and public infrastructure:** Government buildings, hospitals and schools, could suffer the consequences of rising sea levels.

It is essential to note that the impacts of sea-level rise on the economy will vary depending on the particular situation and the adaptation strategies used. Nevertheless, it is clear that the Marchica Lagoon and its economy are seriously threatened by rising sea levels.

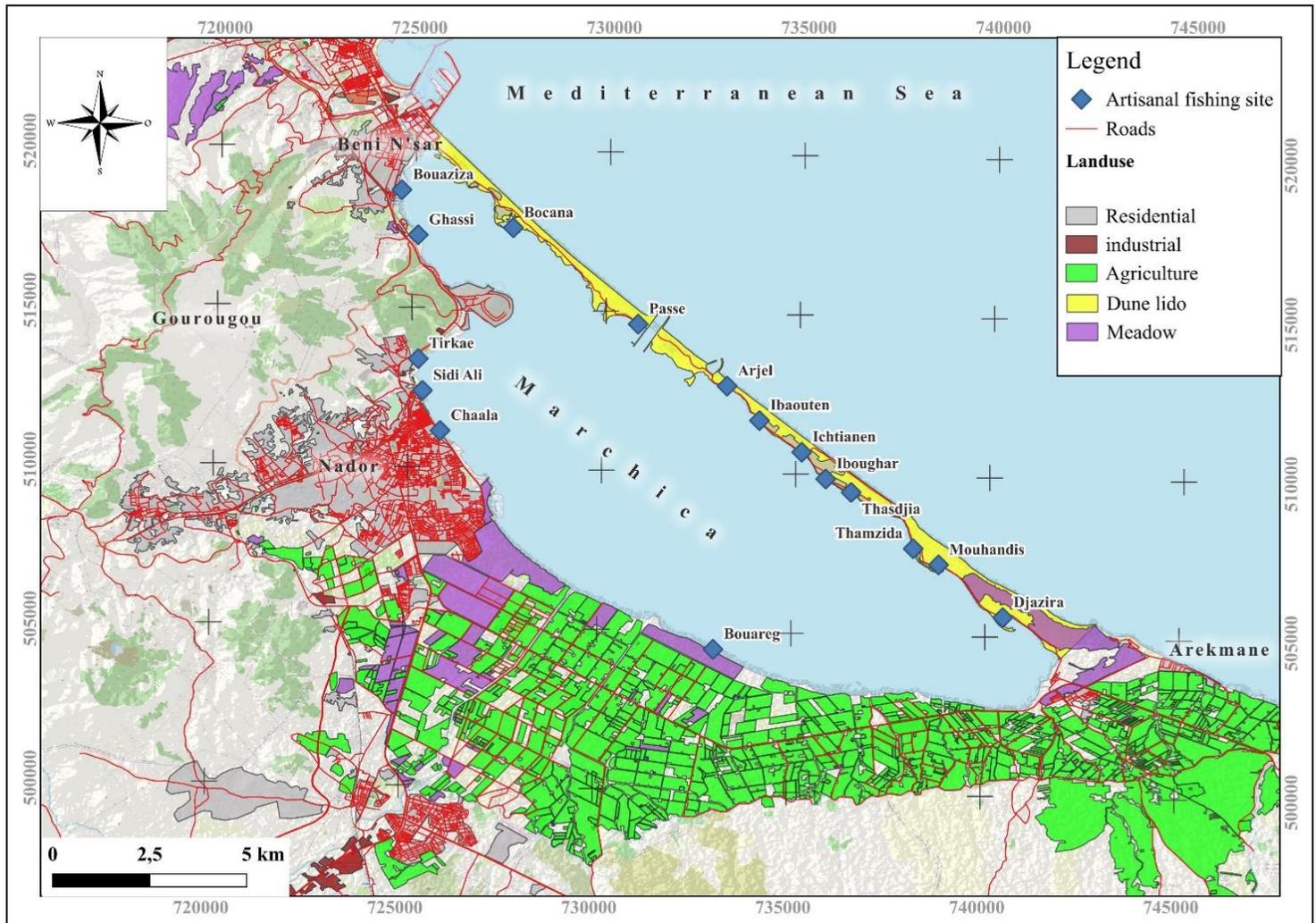


Fig. 3. Map of flood zones as a function of sea level rise for Marchica Lagoon

### Implications for responses

Legislation, policies, and initiatives implemented to mitigate risks and increase resilience to sea-level rise are referred to as sea-level rise responses. These measures include protecting the coastline, addressing the impacts of sea-level rise, coastal retreat, and advancing the ocean through offshore construction and ecosystem-based adaptation. Determining the most appropriate course of action in response to sea-level rise is a complex process that involves multiple governance challenges, as well as political and societal contestation (IPCC, 2019).

The ability of a system to adjust to the impacts of climate change and adapt to its variability and extremes while limiting possible damage is called adaptation (Niazi, 2007) and is taken into account in the vulnerability studies mentioned in the report of the Intergovernmental Panel on Climate Change (IPCC, 2019).

Protection reduces the risks and hazards associated with the coast by preventing the spread of mean or excessive sea level inland and other related effects, including hard protection against flooding, erosion and saltwater intrusion, including dikes, sea dikes,

breakwaters, barriers and dams (Nicholls., 2018), sediment-based protection, such as dunes, beach and shoreline replenishment, and ecosystem-based adaptation. These subcategories are also referred to as hybrid measures, such as a green belt of marsh in front of a dike, or a dike specifically designed to include niches for habitat formation (Coombes *et al.*, 2015).

Adaptation covers a variety of biophysical and institutional measures that, despite increasing risks, enable the habitability of coastal areas by reducing the vulnerability of human activity, ecosystems, coastal populations and the built environment (Photo 3). Building codes, elevation, moving valuables to higher floors, and floating homes and gardens are some of the strategies for adapting to erosion and flooding (Trang, 2016). Changes in land use or the use of salt-tolerant crop types are examples of adaptation to salinity intrusion. Examples of institutional responses to adaptation, include contingency plans, insurance schemes, and withdrawal zones (Nurse *et al.*, 2014; Wong *et al.*, 2014).



**Photo 3.** 3D plan for the development of the Marchica Lagoon

The advance reduces coastal threats to the hinterland and recently elevated land by building toward the sea, creating new land. This involves reclaiming land above sea level by filling it with pumped sand or other infill material, planting vegetation specifically for natural land accretion, and surrounding low-lying areas with dikes; this process is known as land reclamation and requires drainage systems and frequently pumping (Wang *et al.*, 2014; Donchyts *et al.*, 2016) (Photo 4).



**Photo 4.** 3D plan of green landscaping solutions to protect low-lying areas threatened by rising sea levels

Retreat allows for the movement of people, property, and exposed human activities out of the hazardous coastal zone, thereby reducing coastal risk. This includes migration, which is defined as the voluntary movement of a person abroad on a permanent or semi-permanent basis for a minimum period of one year (**Adger *et al.*, 2014**). Additionally, displacement, which describes the unplanned and involuntary migration of people caused by environmental effects (**Black *et al.*, 2013; Islam & Khan, 2018; McLeman, 2018; Mortreux *et al.*, 2018**). Furthermore, relocation, also known as managed retirement, managed realignment, or relocation, is a process that is typically initiated, overseen, and executed by local, state, or federal authorities. It generally involves small sites and/ or populations (**Wong *et al.*, 2014; Hino *et al.*, 2017; Mortreux *et al.*, 2018**).

Ecosystem-based adaptation (EbA) offers a combination of benefits based on restoration, conservation, and sustainable management of ecosystems that both protect and promote (**Van Wesenbeeck *et al.*, 2017**). An example is the preservation or restoration of coastal habitats, such as *Juncus rigidus* and *Zostera noltii* seagrass beds and wetlands. EbA measures function as barriers and retention spaces to protect the coastline by reducing wave action and, in the case of wetlands, preventing the flow of storm surges (**Krauss *et al.*, 2009; Zhang *et al.*, 2012; Vuik *et al.*, 2015; Rupprecht *et al.*, 2017**) and stabilizing and sequestering coastal sediments to raise elevation and reduce erosion rates

(Shepard *et al.*, 2011), as well as accumulating organic matter and litter (Shepard *et al.*, 2011; McIvor *et al.*, 2012a; McIvor *et al.*, 2012b; Cheong *et al.*, 2013; McIvor *et al.*, 2013; Spalding *et al.*, 2014).

### **Environmental governance in the context of sea level rise in the Marchica Lagoon**

Addressing sea level rise challenges in the Marchica Lagoon demands a comprehensive approach. Ensuring long-term sustainability requires an effective environmental governance that incorporates community participation and safeguards local ecosystems. Research on infrastructure and settlements should consider flooding impacts and sea level rise risks. Urban master plans should anticipate climate change effects, prohibiting construction in high-risk zones. Proposed adaptations encompass enhancing fishermen's conditions, preserving fish stocks through a landing point, modernizing fishing fleets, organizing and training fishermen, and protecting the coastal environment from sea level rise and erosion, including stabilizing dunes, reconstructing beaches, and establishing a sea level observatory.

Marchica Lagoon could apply a variety of strategies to cope with sea level rise:

**Land use planning management:** In order to mitigate the impact of future flooding, zoning studies should be carried out to identify the most vulnerable areas and limit growth there. In addition, resilience principles should be integrated into urban planning.

**Coastal protection and ecosystem:** Restoration through the construction of coastal flood prevention infrastructure and the restoration of wetlands, such as *Juncus rigidus* formations and *Zostera noltii* seagrass beds and marshes, which serve as natural barriers against coastal erosion.

**Sustainable water management:** Applying water management techniques related to sea-level rise, such as protecting freshwater supplies and controlling and monitoring groundwater extraction to prevent land subsidence.

**Resilient infrastructure:** Encourage the construction of structures that can survive flooding and install warning systems to warn the public of risks.

**Ecosystem-based adaptation:** Adopt measures to preserve and protect local ecosystems, including wildlife habitats, and support sustainable fishing methods that preserve the natural balance of the lagoon.

**Scientific research for decision-making:** To help decision-makers better understand the impact of sea level rise in the Marchica Lagoon and to contribute to the development of adaptation measures in accordance with standards respecting the Marchica Lagoon ecosystem.

### **CONCLUSION**

In the second section of the IPCC's 6th Assessment Report, published in February 2022, a special attention was paid to sea level rise. Coastal lagoons serve as areas to absorb the power of storms, reducing the intensity and speed of waves. Therefore, the preservation of these ecosystems can serve as an adaptation strategy by minimizing the vulnerability of populations to their impacts.

The Marchica Lagoon is a particularly vulnerable site to the risk of sea level rise due to its particular topographical and socio-economic characteristics. Due to its

submerged coastal topography and proximity to the sea, it is particularly vulnerable to flooding. Marchica faces an increased risk of severe morphological, environmental and economic effects due to sea level rise. Beyond property damage, the effects of marine submersion could also jeopardize the livelihoods of local populations, ecosystems and quality of life in general. These complex impacts will have adverse impacts on a variety of sectors, including critical infrastructure, economic activity, and natural resources. Therefore, the projected effects of sea-level rise on small-scale fisheries underscore the complex and interconnected challenges that small-scale coastal fishing communities are likely to face. The continued rise in sea level reveals several key aspects.

In essence, the projected impacts underscore the urgency of addressing the complex interplay between environmental, socio-economic and infrastructural factors. With sea level rise, a holistic and collaborative approach is crucial to preserve the livelihoods and resilience of small-scale fishing communities in the face of a changing coastal environment.

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**Authors' contributions**

CH. B and M. H carried out the study and wrote the manuscript. B.EL, A.EL & A. S designed and revised the manuscript. All authors have read and contributed with their edits to improve the initial version of the manuscript and have accepted the version currently submitted.