Vulnerability of the Marchica lagoon toward climate change

[1]Chaymae Boujnan, [1]Bouchta El-Moumni, [2]Mimoun Bahkan, [3]Mimoun Chourak, [1]Hajar Bouzaidi, [2]Asmae Aknaf, [3]Adil Jouamaa, [1]Meryam Mostakim

[1] Department of Earth Sciences, Faculty of Sciences and Techniques, University Abdelmalek Essaadi, Old Airport Road, Km 10, Ziaten. BP : 416, Tangier, Morocco; [2] Multidisciplinary Faculty of Nador, University of Mohammed Premier, BP 300, 62700 Selouane, Nador, Morocco; [3] Industrial and Seismic Engineering Research Team, National School of Applied Sciences of Oujda, Mohamed 1st University, 60000 Oujda, Morocco. Corresponding author: C. Boujnan, chaymaeboujnan88@gmail.com

Abstract. This paper provides a general overview of the environmental state of the Marchica lagoon (NE Morocco) in the context of climate change. The focus is mainly on the climate framework, hydrodynamic conditions and biodiversity status, as well as on the anthropogenic pressures related to agriculture, urban development, maritime transport, tourism and fisheries in the lagoon. We highlight the links of climate change impacts to major blue economy sectors and agricultural changes in order to investigate other changes observed over the past decade, specifically in climate variability, the lagoon's water quality and species distribution. According to the present study, the lagoon temperature is likely to rise at an average of 3°C while wet days are expected to decrease at an average of 2 days per year, by 2040.
Key Words: adaptation, climate change, Marchica lagoon, mitigation.

Introduction. The Mediterranean Basin is a constantly changing area facing unequal distribution of resources, social instability, conflict and migration. In addition to these social factors, the Mediterranean Basin is naturally exposed to several hazards, including earthquakes, volcanic eruptions, floods, fires and droughts. In this complex situation, several new challenges have emerged due to climate change impacts such as warming, more severe droughts, changing extreme events, sea-level rise and ocean acidification (IPCC 2013).

These challenges interact with other environmental changes caused by pollution and urban growth. In order to protect these valuable areas from different impacts related to climate change, the Moroccan government has established many agencies to protect and develop the lagoons and coastal areas (examples of agencies: Agency for the development of the Marchica lagoon site, Agency for the development of the Bouregreg valley, Nador west med, Tangier Mediterranean Special Agency).

In this way, they are trying to respond to the world's vision of sustainable development goals by developing the blue economy to protect life below the sea. One of the largest Moroccan coastal ecosystems exposed to this situation is the Marchica lagoon, which is located in the north East of Morocco.

Due to its socio-economic importance in the region, the Marchica lagoon has been subject to various studies which aimed in particular at defining its hydrological and sedimentological systems, fishing and aquaculture (Guelorget et al 1987; Idrissi et al 2003; Arid et al 2005; Lakhdar et al 2005; Abdellaoui et al 2006; Hamoumi 2012).

This lagoon represents a complex and unique coastal ecosystem that requires special attention in the context of policies designed to face climate change impacts. The significant and rapid development of economic activities has generated many sources of pollution and important pressures on the lagoon. This makes the site more vulnerable to the future impacts of climate change (Garnaud & Rochette 2012). In order to deal with the threats of the Marchica natural environment, it has become a privileged site for development cooperation which focused on sustainable management of this area. Indeed, the MedWetCoast project highlights the existence of "sites of biological and ecological interest", Cap Nador reminds the "very high level of biodiversity", while the "Depollution" project raises very strong challenges in terms of biodiversity and of environment. These projects indicated the same sources of environmental degradation within the lagoon which are agricultural pollution, overexploitation of natural resources, urban development, etc. Many policies and visions were established to protect and enhance the water quality in the Marchica lagoon, which is vital for a thriving foundation of aquatic resources and sustainable development of many blue economy sectors, such as fisheries, tourism, and urbanization, among others. This strategy intends to eliminate all the surrounding water discharge and has found an eco-friendly, durable solution that responds to the needs of local communities while respecting Moroccan policies on water and climate change.

So, the Marchica lagoon is considered as a wetland whose vulnerability requires the development of climate change adaptation strategies (ACCMA). The aim of this paper is to present an overview about the status of the Marchica lagoon in order to understand the current environmental conditions and human activities taking place in the area. We then compiled priorities for intervention in order to ultimately arrive at sectoral recommendations for policy makers. Additionally, we took into account Morocco's Nationally Determined Contribution (NDC), which aims to counter the effects of climate change through mitigation and adaptation models. Between 2020 and 2030, Morocco estimates that the cost of implementing adaptation projects for the water, forestry and agriculture sectors will be a minimum of USD 35 billion (Morocco NDC 2018).

Material and Method. This paper reports on a conceptual adaptation model for the studied sectors that we developed, as shown in Figure 1. This model presents the outcomes of applying adaptation models to various sectors in the Marchica lagoon and how it can be controlled for achieving the NDC targets and fulfilling Morocco's 2030 climate pledge.

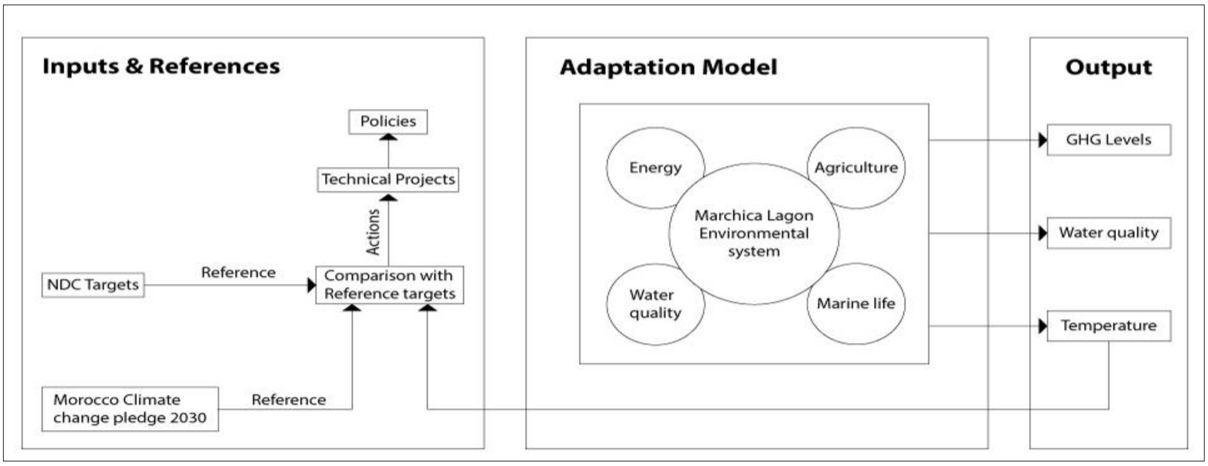

Figure 1. Adaptation model for climate change in the Marchica lagoon.

Description of the study sites. Nador lagoon called also Marchica lagoon or Sebkha Bou Areg is located on the Northeast coast of Morocco, precisely between the latitudes 35°05′N and 35°14′N and the longitudes 2°44′W and 2°56′W (Figure 2). This lagoon is characterized by its biological, ecological and economic interests (Aknaf et al 2015), the second-largest wetland in the Mediterranean basin and the largest lagoon in Morocco (Garnaud & Rochette 2012), with a length of 25 km, a width of 7.5 km and an estimated area of 14 000 ha (115 Km²) (Mohammed VI Foundation for Environmental Protection 2019).

Figure 2. Location map of the study area in the NW Moroccan Mediterranean (Google Earth 2022).

The lagoon is separated from the sea by a coastal dune and connects with the Mediterranean Sea through a new artificial channel of 300 m in width and 7 m in depth. Administratively, the Marchica lagoon belongs to four municipalities: two are urban (Nador and Beni Ansar) and two are rural (Bouareg and Arekman).

As this zone is rich in terms of biodiversity and has particular habitats for fauna and flora, the Marchica lagoon has been classified as a biological and ecological site of interest since 1996 and a Ramsar site of wetlands conservation and protection since 2005 (Aknaf et al 2022). In fact, the mixture of marine and continental water makes the lagoon a single system with high ichthyological and microalgal diversity that is rich in complex food chains (INRH 2018).

Four main coastal management projects have been funded since 2000 for the sustainable management of the Marchica lagoon (Rochette & Comley 2015):

- the project “MedWet Coast: Conservation of Wetland and Coastal Ecosystems in the Mediterranean Region” (2000-2005), funded by the United Nations Environmental Program (UNEP) and the French Global Environment Facility (FFEM);
- the “Cap Nador”: an Integrated Coastal Zone Management (ICZM) approach for the sustainable development of the coast of the province of Nador, Morocco (2006-2008), funded by the European Union and its Short and Medium Priority Action Program terms for the environment (SMAP III);
- the “ACCMA: Adaptation to climate change in Morocco” project (2007-2010), financed by the UK Department for International Cooperation (DFID) and the Canadian Center for International Development (IDRC);
- the “Depollution project: support for the implementation of a global depollution plan and the protection of the Marchica lagoon” (2008-2011).

Without a direct link to the planning documents, these management plans had very little influence on the territory planning. Then, Marchica Med was created. This latter has become the dominant structure in the development of the lagoon policy. However, it is clear that the ICZM (Integrated Coastal Zone Management) and climate change adaptation projects developed since the creation of Marchica Med have not succeeded in integrating this actor or in registering their actions in the development program.

Natural conditions / environment

Climate framework. Morocco is generally characterized by a semi-arid climate; however, the coastal areas are temperate (Maroc Meteo 2019). The study area is characterized by a dry and hot summer and a rainy and cool winter.

Precipitation. The wet period corresponds to the months of October to April, with higher peaks in the months of October and November (average 64.37-54.26 mm) between 2006 and 2016 (PMC-Nador 2018); while the driest months are from May to September, with negative peaks in the months of June and July are 6.4 and 6.2 mm respectively. Snow is absent, with some hail events (Dakki et al 2003).

Temperature. The maximum temperature was 39.17°C during the period between 2006 and 2016 (CPMN-Nador 2018). The minimum temperature is 22.9°C. The hottest months are June, July and August; while the coldest months are between December and March.

Humidity and evaporation. The average relative recorded humidity is 71.25%, which shows the fairly high humidity that the area can experience. The wettest month is October, with an average monthly humidity of 74.6%; while August is the least humid, with 69% relative humidity (Maroc Meteo 2018).

Hydrodynamic characteristics. The external hydrodynamics of this coastal area depend on the tidal regime, the littoral drift currents and the prevailing waves. The internal hydrodynamics of the Marchica lagoon is connected to three types of water sources that directly influence the water quality (Mohammed VI Foundation for Environmental Protection 2019):

- the marine water, always dominant, enters through the artificial inlet;
- the treated water discharged from the wastewater treatment plant (referred to here as STEP), which serves Grand Nador and Beni + Ansar. A new one is almost done;
- the hydrogeological contributions and surface water inputs from periodic flows, often small streams.

The Marchica lagoon is a true model of transgressive barrier island system. It develops in a microtidal environment, where the energies of the waves, amplified by storms and winds, play an important role. The barrier island therefore presents an asymmetry which translates the existence of two domains where the hydrodynamic and dynamic sedimentary processes are different: a moderate reflective domain and a moderate dissipative domain (Saddik et al 2017). A new entrance pass was created in the lagoon to allow a better exchange of the waters of the lagoon with the Mediterranean waters (Hilmi et al 2015). It has been operational since 2011.

The combination of these two climatic factors, temperature and rainfall for the period 2006-2016, makes it possible to determine, from the umbrothermal diagram (Figure 3), the wet and dry periods in the study area. The first is spread over 6 months (October-March) and the second extends over 6 months (April-September).

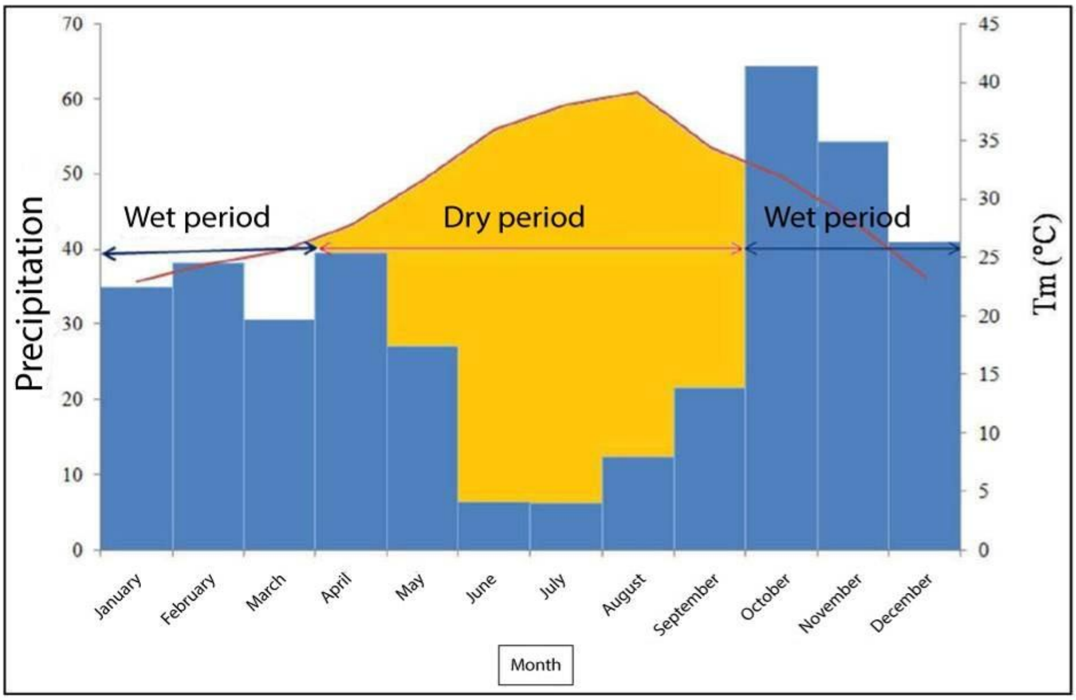

Figure 3. Umbrothermal diagram of the study area (2006-2016) (Aknaf 2018).

Biodiversity status. The Marchica lagoon is rich in terms of biodiversity and is officially confirmed by its inclusion in 2005 in the list of wetlands of international importance.

Ichthyological biodiversity. Compiled information on the historical and current data of the Marchica lagoon reveals a total of 90 species, which represents approximately 45% of the specific ichthyological wealth reported in the Atlantic-Mediterranean lagoons (INRH 2018). Based on some multi-variable analyses in previous studies, two significantly distinct biological ichthyological groups have been identified.

The shallow areas record the highest specific ichthyological richness, abundance and biomass. In fact, the shallow water assemblages in the Marchica lagoon are dominated by fish (Jaafour et al 2015) and four new species identified by Selfati et al (2018) such as *Epinephelus marginatus*, *Epinephelus costae*, *Epinephelus caninus* and *Mycteroperca rubra*. But because of occupancy dynamics and the seasonal changes in the structure of ichthyological assemblages in each of them are under the influence of environmental factors (Becheker et al 2022) and a higher marine influence (Selfati et al 2019).

Macroalgal and phanerogamae biodiversity. Based on the literature review, Gonzalez & Conde (1991) conclude that green algae (Chlorophyceae) represent 31 species, 62 red algae (Rhodophyceae) and 18 brown algae (Phaeophyceae). While a recent study which was conducted by Aknaf et al (2022), identified a total number of taxa includes 59 species, of which 26 species of Chlorophyceae, 29 species of Rhodophyceae and 4 Fucophyceae, in addition to two species of flowering plants: *Cymodocea nodosa* and *Zostera noltei*. This difference is probably caused by climate change in addition to the intralagunal development that was carried out in 2011 to clean up the lagoon.

About the richness and spatial distribution of the algae, presented in Figure 4, are characterized by a maximum of 38 species observed at station 3 near the new pass. This station is close to the exchange of water between the lagoon and the Mediterranean Sea and a minimum of 10 species were noted in the south of the lagoon (station 7).

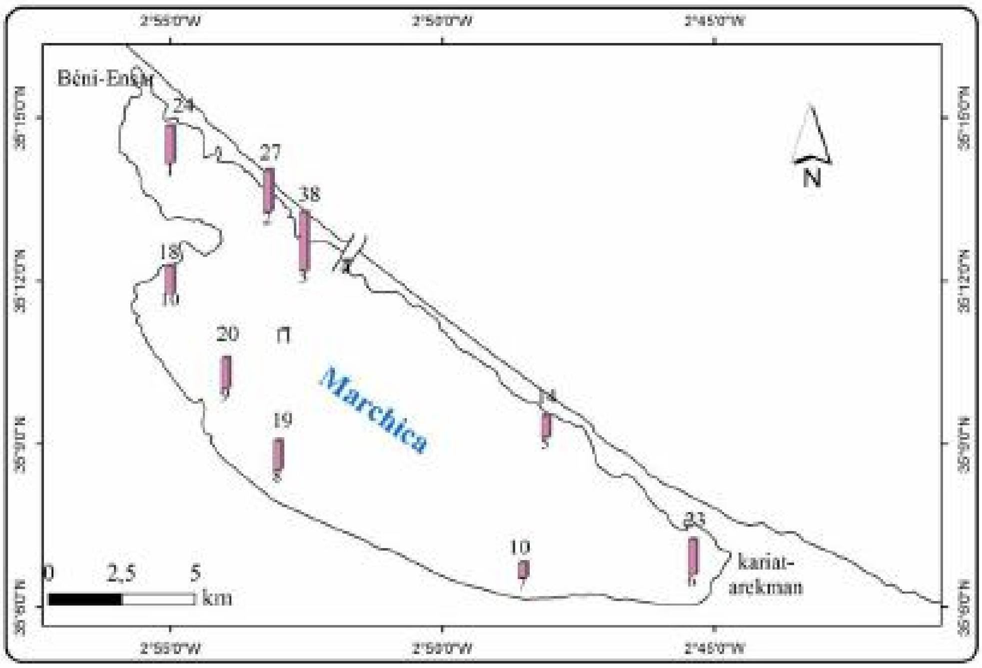

Figure 4. Spatial distribution of macroalgae in Marchica lagoon (Aknaf et al 2022).

The study from the literature review that was carried out in November 2007 identified a total of 311 phytoplankton species belonging to seven groups: 133 diatom species, 169 dinoflagellates, 2 Cyanophyceae, 2 Dictyochophyceae, 1 Euglenophyceae, 1 Chlorophyceae, 1 coccolithophorid species and 1 Raphidophyceae (El Madani et al 2011).

Our study has identified only 58 phytoplankton species, based on the data set provided by INRH from their November 2018 campaign. Among the seven groups identified in the 2007 campaign, only four groups were found in the 2018 campaign: 31 diatoms, 22 dinoflagellates, 1 Euglenophyceae and 1 Dictyochophyceae.

The minimum phytoplankton taxa abundance was observed in the area of Kariat Arkman, where there is less water circulation; and the maximum taxa abundance is observed around the area of the new artificial gateway, where there is a greater exchange of water between the lagoon and open sea. This may explain the intolerance of phytoplankton to the highest amounts of turbidity that exist mainly around Caballo, Selouane Wadis and confined zones. In light of these observations, the efficient role played by the new 2013 gateway is reflected by the changes in phytoplankton distribution and abundance over all areas of the Marchica lagoon.

Comparing the 2007-2008 and 2018 campaigns, differences are observed in phytoplankton taxa abundance, as shown by the histograms represented in Figure 5. Based on the literature review, the highest abundance of phytoplankton blooms for the 2007-2008 campaign was recorded in summer 2018 with a 99.9% contribution from *Nitzschia longissima*, which may be explained by the summer stratification and anthropogenic influence coming mainly from the Beni Ansar wastewater. In summer, a high abundance of this species was recorded. However, a reduction in *N. longissima* abundance was observed by our study when considering the November 2018 campaign. This may be explained by differences in the meteorological conditions, as our assessment was done in a winter campaign. It may also be explained by the fact that in November 2018 the Marchica lagoon was slightly eutrophicated, with a tendency to increase as summer approaches due to the increasing temperature, light intensity and nutrient enrichment amplified by the impacts of summer stratification. However, the second hypothesis cannot be confirmed in all the lagoon's areas. The dominance of *Leptocylindrus minimus* in the diatom group was observed around the area of Beni Ansar city. The high abundance of this species reflects nutrient enrichment and a total chlorophyll increase in this area, as its abundance increases with increasing nitrate concentration (Alves-de-Souza et al 2008), temperature, salinity and total chlorophyll-*a* (Pizarro et al 1997). This enrichment may be explained by the fact that this area is confined and receives less water circulation.

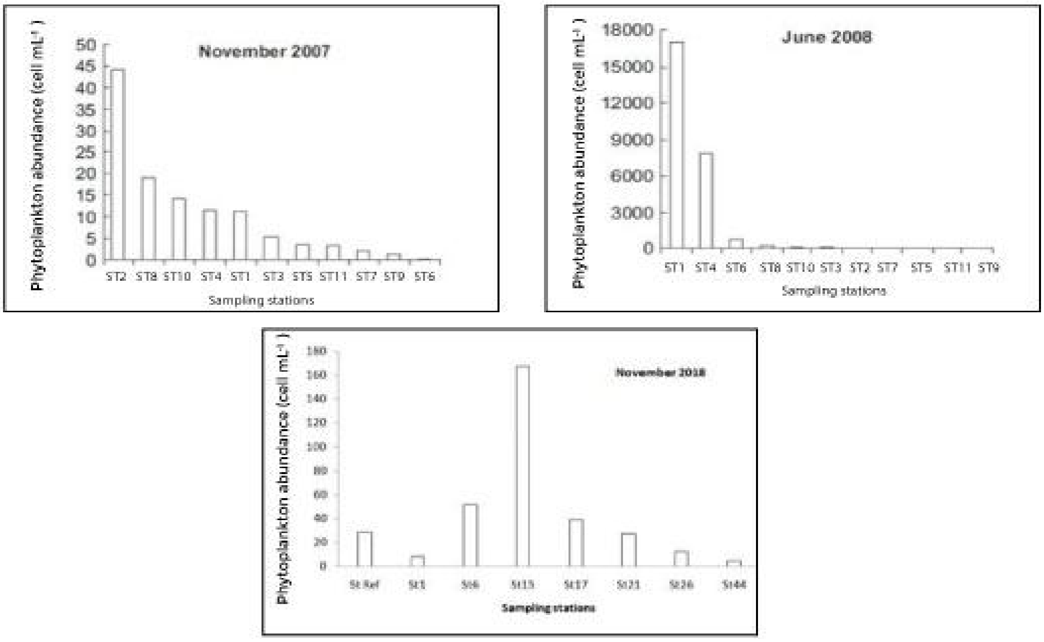

Figure 5. Spatial variation in phytoplankton abundance over one decade 2007-2018.

To conclude, based on phytoplankton abundance assessment, several hypotheses have been put forth to explain the reduction in phytoplankton abundance over the years. All of them highlight that the new gateway, anthropogenic inputs and meteorological variability in the Marchica lagoon have an influence on the phytoplankton composition, abundance and their spatial and temporal distribution.

Anthropogenic pressures*.* The lagoon was submitted in the past to anthropic pressures related mainly to population growth, urban, industrial and agricultural discharges and to various economic activities carried out in the lagoon site (Mohammed VI Foundation for Environmental Protection 2019).

The lagoon faces several anthropogenic pressures (Garnaud & Rochette 2012). The main activities taking place both within and around the Marchica lagoon are depicted in Figure 6.

Agriculture. The first main activity along the lagoon's inner shores is agriculture, with vast stretches of land divided into smaller crop areas extending over 15 km in length and over 7 km landwards. For all the municipalities surrounding the lagoon, the human force working in agriculture, livestock and fisheries represents 11.8% of the total labor. The use of phytosanitary products for agriculture damages the quality of water of the lagoon (Garnaud & Rochette 2012). In addition to the agriculture sector, forest areas are also widely present in the lagoon's surroundings.

Urban development. The city of Nador is a major urban and port center (Garnaud & Rochette 2012). The strong urban and industrial development of the region leads to significant pollution by discharges of untreated wastewater. The lagoon was submitted to a strong pressure from population of more than 200,000 inhabitants (Mohammed VI Foundation for Environmental Protection 2019).

Maritime transport. Two main commercial ports are located on the north-eastern edge of the lagoon. Heavy traffic flow mainly reflects traffic exchange with Spain and France (Figure 6). Melilla port, located in the Spanish Autonomous region of Melilla, is both a cargo and passenger port. On its southern border lies the Moroccan port of Beni Ansar, one of the main commercial ports in the country, and it mainly serves the city of Nador via the nearby railway network. This port is also adjacent to an industrial zone to its south. Light traffic activity can be detected within the bay itself, mainly reaching the city of Nador and the Atalayoun peninsula. This is most likely due to tourist vessels entering the lagoon. On another note, the Nador West Med Port located in the Bouyafar region, scheduled for completion in 2023, will also become a major transport hub in the region. Although farther away, its operation will likely take pressure off of the Beni Ansar commercial port, which in turn will be redeveloped to serve passenger traffic and recreational activities. This aligns with the long-term vision developed for Marchica lagoon (Oxford Business Group 2014).

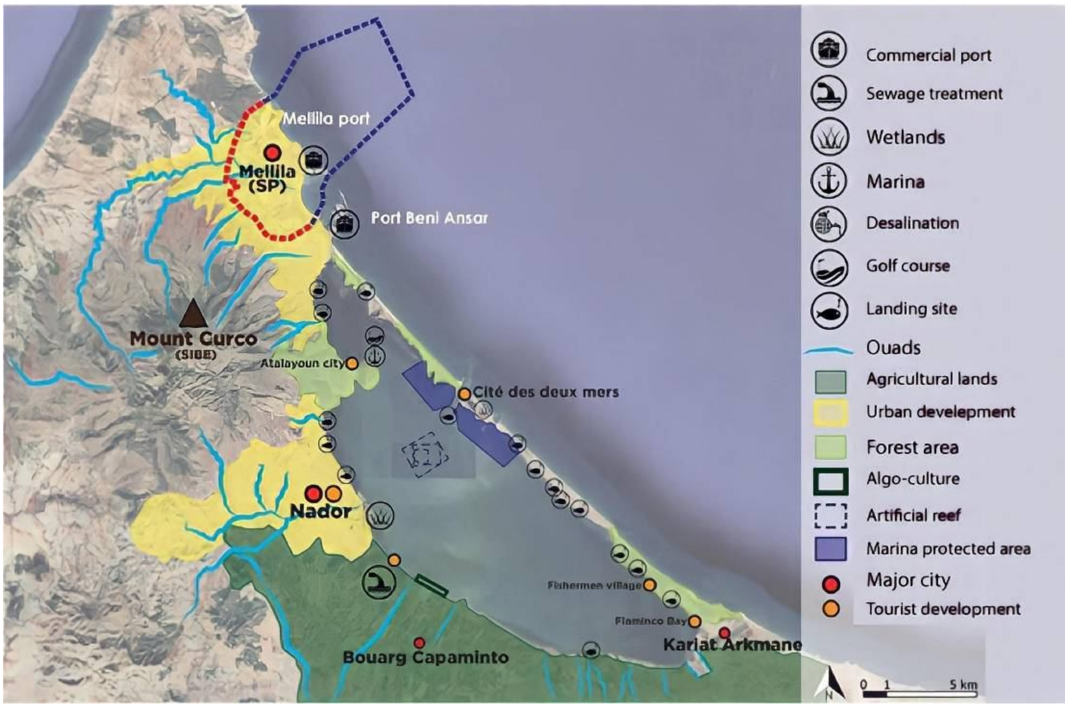

Figure 6. Land use and maritime activities map of the Marchica lagoon.

Tourism and coastal development. In 2009, Morocco's government launched the Vision 2020 Plan, in which Marchica and Nador West are significant Mediterranean examples for testing new territorial policies based on emergent mega-projects for a "globalizing city-region" (Kanai & Kutz 2011). The development of tourism in the Marchica lagoon is increasingly gaining momentum. In fact, the northern side of the lagoon already has the infrastructure to host certain touristic activities, with three small marinas/ports located on the northern half (mainly for recreational and fishing purposes). On the other hand, the southern coastal community has no direct access to the sea (no ports, no touristic facilities and no maritime activities, etc.). This indicates an imbalance that may lead to future seasonal conflicts (uneven tourist pressure distribution, which leads to pressure on the ecosystems as well). In fact, one new project around Marchica lagoon is the Marchica Med development, a large-scale project with dual purposes: tourist development and an environmental depollution and rehabilitation project. Developing a destination that will attract a large number of visitors in a very short time may cause stress to the natural environment and lead to its degradation. For this reason, any planning should be done through an integrated process that considers the ecosystem's parameters, the time factor and overall sustainability goals. Growing pressure from tourism and too little waste treatment capacity justified the classification of the site as a "hot spot" of pollution by the Mediterranean Action Plan (MAP).

Fisheries. As far as fisheries are concerned today, artisanal fisheries are the main socio-economic activity taking place in the lagoon. Several landing sites are distributed along both shores of the lagoon. Some species are exploited in the lagoon and exported to the Spanish market. As for pisciculture, one farm (Marost) carried this out in the period 1985-2006 in the Marchica lagoon. It produced mainly fish (sea-bream *Sparus aurata* and sea-bass *Dicentrarchus labrax*), but also, to a lesser extent, bivalves (flat oyster *Ostrea edulis* and European soft clam *Corbula gibba*) and shrimps (Mediterranean shrimp *Sicyonia carinata* and Japanese prawn *Marsupenaeus japonicus*), therefore the activity of artisanal fishing, is the main socio-economic activity practiced in this lagoon, but is therefore considered a serious threat to sustainability, due to the lack of control and management of data collection on the different aspects biological and socio-economic aspects of this fishery (Demiathi et al 2022).

In 2016, a macroalgae cultivation project was launched in Bou-Areg (south of the Marchica lagoon) and extends over an area of 28 ha to the east of the new Grand Nador wastewater treatment plant.

On the scale of rural municipalities, the sector employing more people is obviously that of agriculture, livestock and fisheries; while for the urban communities, trade is ranked first (FAO 2017).

***Analysis methods**: **used model**.* The present study methodology is based on an assessment model. First, we conducted an overall assessment of the lagoon's current environmental condition and anthropogenic features. Then, we carried out a detailed analysis of the impacts caused by direct human activities and human-induced climate change. This assessment will allow prioritizing measures to be taken, followed by developing set of guidelines and recommendations for policy makers, thus helping them mitigate and adapt to the current and upcoming climate change impacts. The assessment also aims to understand the urgency of the situation and pinpoint the main areas of intervention.

The Marchica lagoon is suffering from impacts that are both anthropogenic and ecological in nature. Climate change is overarching and affects both human activities and natural conditions in the lagoon. Understanding the relationships between these components is crucial for addressing each impact. To proceed with this assessment in each sector, we collected databases from the literature, consultancies and archives. Only data with relevant corresponding metadata about sampling location, date and methods has been included. We collected data from previous in-field surveys in order to prove, on the one hand, the positive impact on water quality from creating a new gateway and new wastewater treatment plants, and, on the other hand, the efficiency of policies that have been set to reduce the damaging impact of climate change and water discharges. The adopted in-field data were collected from the geoscience laboratory "MARCHICA" at the end of 2014 and mid-2015, along with other data provided by INRH. During this campaign, many parameters such as temperature, salinity, dissolved oxygen, total suspended matter (TSM), and nitrate concentration have been analyzed. Data manipulation and submerged aquatic flora distribution patterns were provided by GIS software.

Based on data gathered from a literature review on the abundance and distribution of phytoplankton and macroalgae in previous years, we assessed this abundance and distribution using spatial distribution maps. These maps show the quantification of phytoplankton taxa during an investigation conducted in November 2018 and the spatial distribution map of fresh macroalgal biomass measured in the same period. Then we compared the quantified taxa map with the phytoplankton taxa number map that was determined during the period 2007-2008.

As vegetated habitats are great providers of oxygen in water, our spatial distribution maps of fresh macroalgal biomass are compared with the spatial distribution maps of dissolved oxygen levels at the surface. This comparison allows us to identify correlations between variations in macroalgae distribution and in dissolved oxygen levels in the lagoon. After defining the main issues related to direct anthropogenic intervention and indirect climate change impacts, general guidelines and recommendations are listed according to their sector category.

Results and Discussion

Analysis of the status of the Marchica lagoon toward climate change**.** In order to understand the climate variability, two different categories of data have been considered. The first category was collected from the climate information platform, and the second one from climate-data. The variation and evolution of the selected variables over the years have provided an overview of the changes in climate variability (Figure 7).

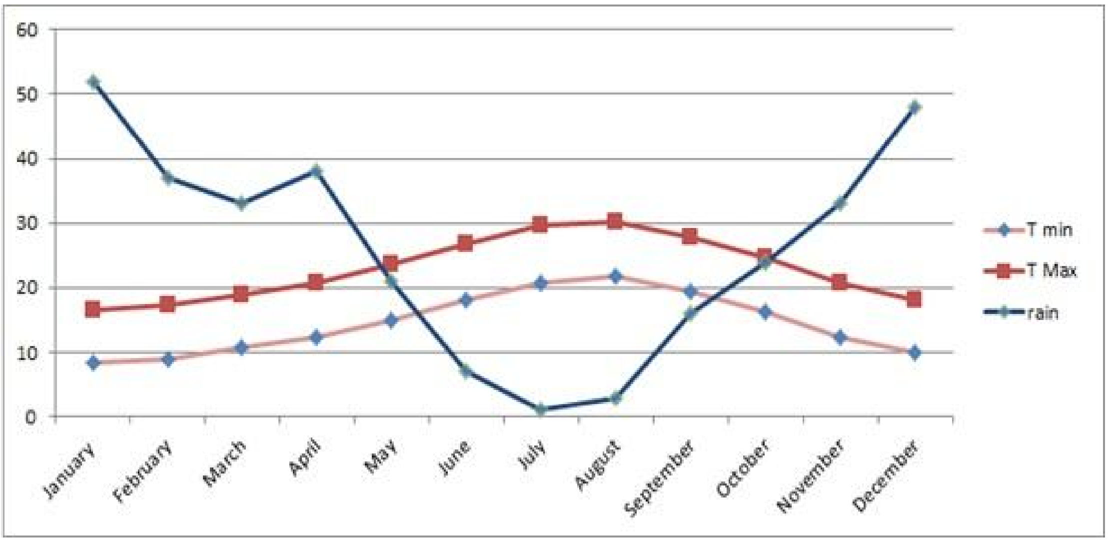

Figure 7. The actual climate variation 2019.

Based on the data that is available from the climate information platform regarding the variation in parameters recorded from 1980 to 2000, the coldest month is January with a minimum of 10°C, and the warmest month is august with a maximum of 30°C. Concerning the monthly rainfall, January is the rainiest month, with an average of 50 mm, and the lowest month is July, with an average of 3 mm.

The Figure 7 presents the max/min temperatures and monthly rainfall from the climate-data portal. As shown, the maximum temperature is 30.1°C, recorded in august with a minimum of 8.4°C, recorded in January. An average increase of 1°C occurs within the maximum temperature, and an average decrease of 3.6°C takes place in the minimum temperature. For the monthly rainfall, the current data show that precipitation is more stable and represents an increase of 2 mm. The monthly rainfall is the same, as January is the rainiest month, with an average of 52 mm; and July is the least rainy month, with an average of 1 mm.

About the dissolved oxygen (Figure 8) content in the surface waters of the lagoon it shows temporal variability, the highest concentrations were analyzed during winter in the south (10.61 mg L^{-1}) and southwest (12.75 mg L^{-1}) of the lagoon. However, the lowest content was found in summer 2015 (2.5 mg L^{-1}) in the southeast of the lagoon (Aknaf et al 2017).

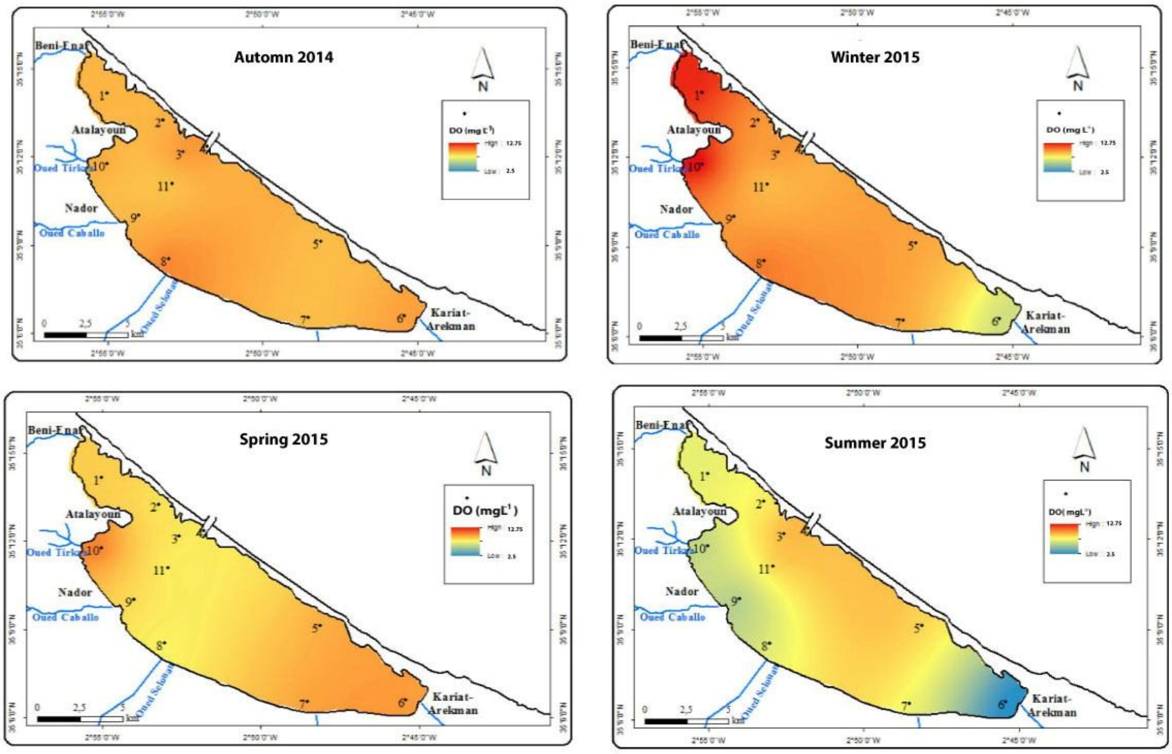

Figure 8. Spatial-temporal distribution maps for dissolved oxygen amounts in 2014-2015 (Aknaf et al 2017).

Projected changes in climate variability in the lagoon. We have calculated many anomalies and parameters for the period 1980-2000 and have developed a projection on climate variability by forecasting some climatic parameters for 2020 to 2040, mainly precipitation and maximum temperature in the Marchica lagoon. These variables are calculated from different stations located near the lagoon (Melilla, altitude 55 m; Nador, altitude 177 m). The increases and decreases in our estimates of these parameters allowed us to identify some environmental issues related mainly to the influence of climate crisis on weather, soil and wind.

Monthly rainfall. The projected monthly rainfall calculation is based on observations recorded from 1980 to 2000 in Melilla city, and it shows that by 2040 the total monthly rainfall will decrease by 18 mm in January and will be almost negligible in the summer season (June, July and August). However, total monthly rainfall is expected to increase in April, March and December (Figure 9).

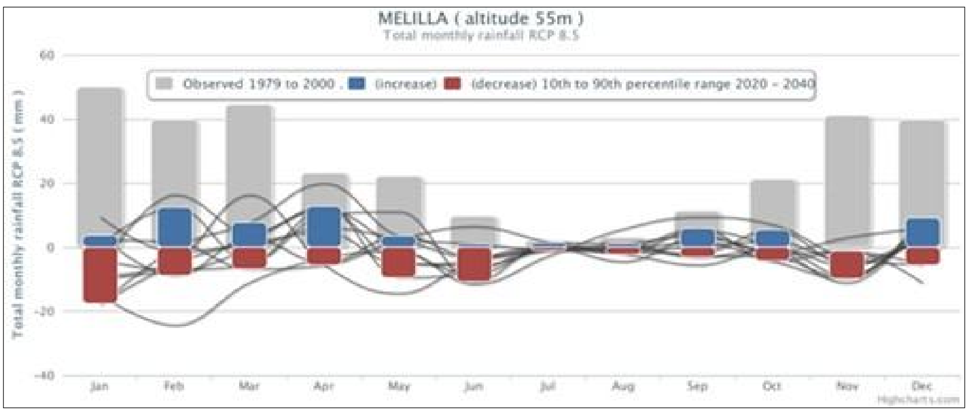

Figure 9. Observed and projected monthly rainfall from, respectively, 1979 to 2000 and 2020 to 2040 meteorological stations.

Maximum temperature. The projected maximum temperature in the region will experience a remarkable increase, with an average of 3°C for each month; this increase will lead to more wet days and water scarcity. The summer months of June, July and August will undergo the most important changes in the region, meaning that the projected maximum temperatures will lead to very hot summers, as shown in Figure 10.

Figure 10. Observed and projected maximum temperature from 1979 to 2000 and from 2020 to 2040 meteorological stations.

Wet days. The projected wet days also indicate some changes due to the impacts of climate change. The months of January and June will see an average decrease of 2 wet days, whereas the month of February will see either an increase or decrease in wet days, as the climate of this region is not stable at this time of year. In general, wet days will balance between increases and decreases over the years (Figure 11).

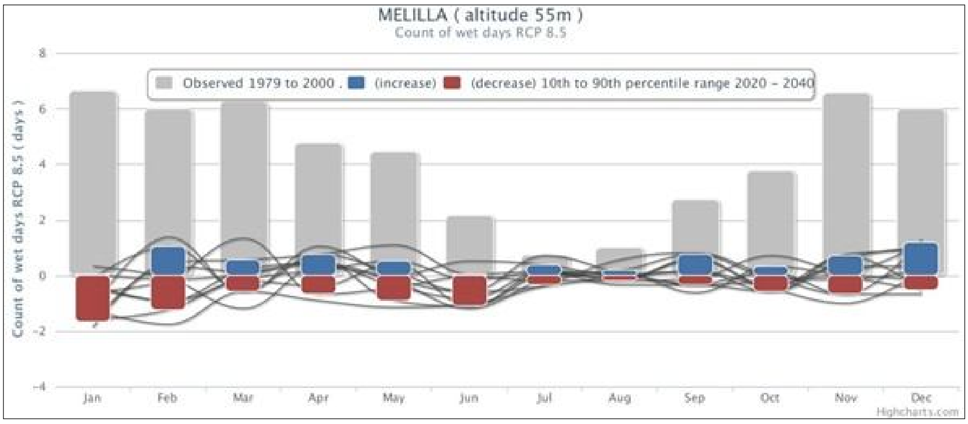

Figure 11. Observed and projected numbers of wet days from 1979 to 2000 and from 2020 to 2040 meteorological stations.

Projected impacts of climate change and extreme climatic events on the lagoon and its surrounding

Coastal floods. According to the analyzed data, the coastal flood hazard in the city of Nador is classified as medium. The geographic location of the city is protected by two capes in the Mediterranean Basin, which play an important role in balancing water movements and hydrodynamics. However, in the event of a coastal flood and sea level rise due to climate change impacts, the Marchica lagoon will be affected and perhaps disappear from the map, especially the areas of Bokana and Beni Ansar.

River floods. Model projections are inconsistent in their estimates of changes in rainfall due to climate change, which may also cause the present hazard level to increase in the future. In the Oriental region of Morocco, particularly in the City of Nadorite River flood hazard is classified as low due to the altitude of the surrounding basins and the precipitation.

Water scarcity. Water scarcity is classified at a medium level in the city of Nador. Based on this projection, the impact of drought will certainly affect the region, especially its agriculture and livestock farming, which are pivotal to its economy.

This situation requires that the local community collaborate efficiently with public and private stakeholders. The present hazard level may increase in the future due to the effects of climate change. Therefore, the creation of a desalination plant as an alternative water source is recommended.

Extreme heat. According to the most recent assessment report by the Intergovernmental Panel on Climate Change (IPCC 2013), continued emissions of greenhouse gases will cause further warming worldwide, and it is virtually certain that there will be more frequent hot temperature extremes over most land areas during the next fifty years. Warming will not be regionally uniform. In the lagoon area, the temperature will increase in the next fifty years and be slightly higher than the worldwide average.

Wildfires. Modeled projections on climate variability have identified a likely increase in the frequency of fire occurrence in the lagoon's region, including an increase in temperature and greater variance in rainfall. In this sense, damage cannot occur only due to direct flame and heat exposure but may also include ember storms and low-level surface fires. In extreme fire weather events, strong winds and windborne debris may weaken the integrity of infrastructures around the Marchica lagoon.

Greenhouse emissions. The Figure 12 represents the growth rate of CO_2 emissions and its projection until 2030. It was conducted based on the NDC targets for Morocco, which was submitted to the United Nations Framework Convention on Climate Change (UNFCCC).

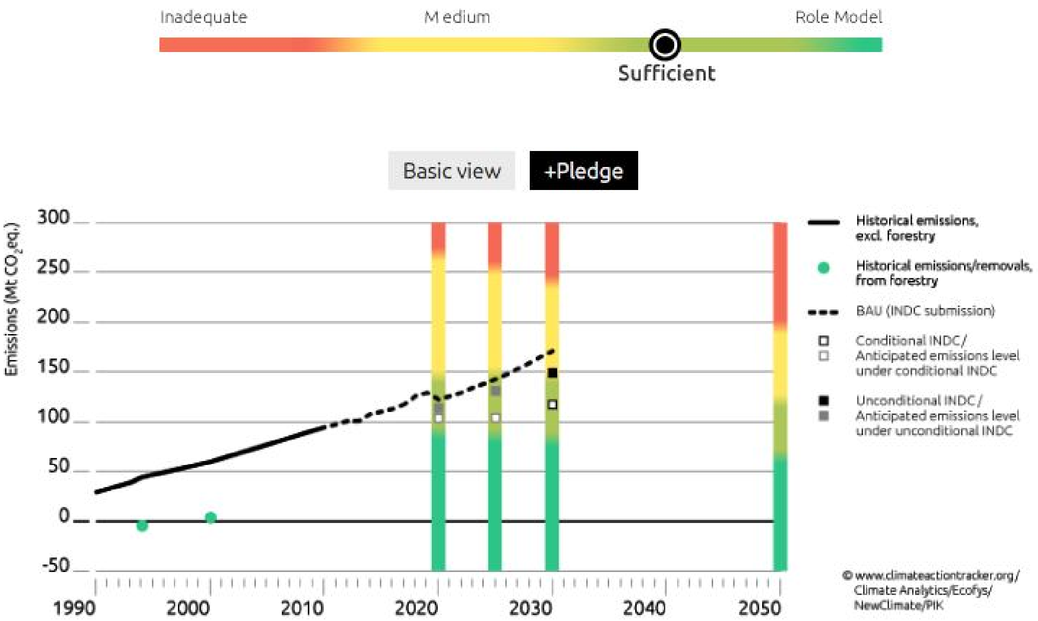

Figure 12. Greenhouse emissions in Morocco until 2030 (https://climateanalytics.org/latest/climate-action-tracker-update-morocco/).

As shown in the Figure 12, a drastic linear increase is evident in the emissions percentage until 2012, when certain policies were applied in order to sustain the NDC targets and maintain emissions levels that do not exceed the green zone indicated by the bars representing Morocco's climate pledge to become "1.5^{o}C Paris Agreement compatible". However, these results will not move to the indicated blue line in the graph unless Morocco's adaptation and mitigation policies for climate change are technically applied and the outcomes of these policies are monitored throughout the studied period.

This paper suggests practices for the agriculture sector's adaptation to the NDC goals and 2030 climate pledge, as this is the most dominant sector in the Marchica lagoon and constitutes the main source of greenhouse emissions in the region.

Recommendations for climate change adaptation and mitigation. The recommendations in this study follow a rather sectoral approach in which measures address specific practices. Similar examples are used to promote best practices.

It is worth noting that some measures, namely restoration and defining conservation areas, are cross-cutting and have a positive impact on all sectors. Some cross-cutting recommendations are explored for climate-informed coastal and marine planning (Gregg 2017), and these include the following:

- setting different time horizons for planning (short, medium, long term);
- returning to traditional knowledge and values;
- adjusting data regularly to reflect changes;
- emphasizing connections between coastal and marine systems;
- reducing development in vulnerable areas;
- increasing stakeholder involvement;
- integrating climate change-related information;
- monitoring and adaptive management.

The following sections will elaborate on more specific sectoral recommendations for activities that are specific to the Marchica lagoon.

Agriculture. The leading sector in water use and polluting discharges in the Marchica lagoon is agriculture. For this reason, applying different management measures to the different operational phases of the sector can help adapt to climate change impacts:

- setting up a monitoring system for greenhouse gas (GHG) emissions and conducting forecasting studies for the effect of GHG on climate change in the region;
- using new crop varieties and technologies in order to reduce adverse impacts from climate change and thus stabilize agricultural output;
- building and enhancing wastewater treatment plants. The reuse of water can also provide an opportunity to reduce pressure on freshwater resources.

The water storage element is also used to ensure the continuity of supply during night hours and on cloudy days. Their total cost has also been found to be almost half that of using batteries for energy storage. This system can be upgraded according to available funds and coupled with existing power sources for the water treatment plant.

Consequently, a fully sustainable energy system can be built as the main source of power for agriculture activities and reduce water treatment plants' dependence on grid electricity and diesel generators. The steps for implementing this system are shown in Figure 13.

Finally, we suggest that greenhouse emissions be fully monitored in order to apply the adaptation and mitigation models for this region's climate change targets. The system for monitoring and generating the analytical results is composed of three main devices:

- a manometer;
- differential absorption lidar;
- an atmospheric chemistry experiment Fourier-transform spectrometer (ACE-FTS).

These devices measure the greenhouse gas components of, respectively, carbon dioxide, methane and nitrogen dioxide.

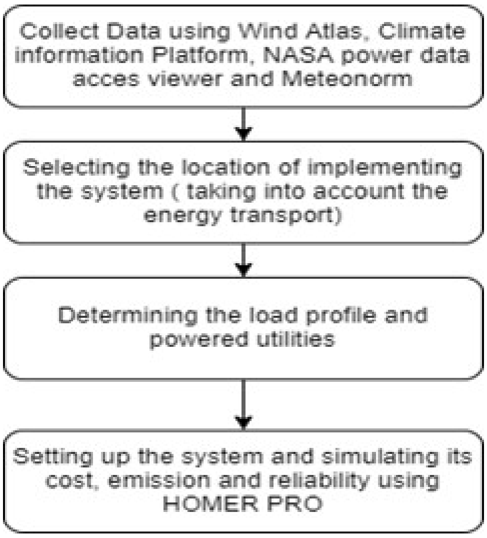

Figure 13. System model creation.

This system consists mainly of field sensors to inform a watchdog list for emissions in the region and conduct forecasting studies on the impact of GHG on other environmental factors. Consequently, we have generated a full database to be embedded in the adaptation and mitigation models and for comparison with the reference setpoints, as shown in Figure 14.

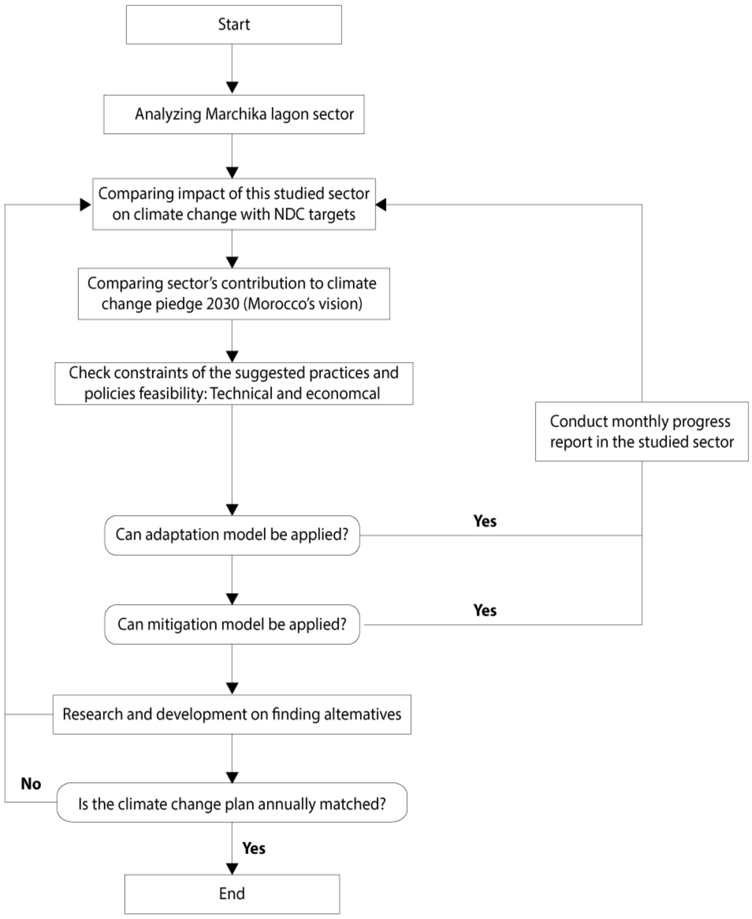

Figure 14. Sequence of adaptation and mitigation practices flowchart.

Coastal development and tourism. Climate change is known to be a catalyst for man-made damage to the ecosystem, particularly in relation to coastal environments. Learning from similar lagoons around the world can help anticipate potential issues and propose measures for avoiding further damage to the ecosystem. Highly comparable to the Marchica lagoon, the Mar Menor (Spain) serves as a perfect example.

In fact, studies have shown changes in wetland biodiversity values and the distribution of certain species caused by land use modifications linked to tourism and other activities (Fernandez 2014).

Moreover, specific tourism-related activities directly affect the natural environment and impede its natural regeneration: golf resorts overusing freshwater resources and dredging for artificial beaches might lead to coastal erosion and habitat destruction (Lloret et al 2015). For this reason, several measures are proposed:

- setting a carrying capacity limit to avoid congestion during high seasons and their resulting impacts on the environment;

- promoting winter activities to avoid having “ghost towns” and uneven distribution of pressures across the year. This can help balance the pressure of human activities on the ecosystem, plus it can promote a sustainable socioeconomic model for local residents;

- constructing buffer zones along the coastal boundary while taking into consideration the projected sea level rise in order to protect tenants from natural hazards;

- developing sustainable engineering solutions, when needed, to reduce damage to intertidal and wetland ecosystems (i.e., geo bags instead of groins; floating breakwaters instead of concrete) (Neelamani 2018).

Maritime transport. Norway’s case of newly imposed regulations for limiting the impact of large ships on their sensitive fjords (is a long, deep, narrow body of water that reaches far inland can be used as an example of potential measures that can be applied within the lagoon (Norwegian Maritime Authority 2017). Two of these are: establishing a low emissions zone within the lagoon by setting regulations for the type of carburant used by larger ships, thus reducing the amount of toxic emissions in the air (low sulphur); and setting speed limits to reduce emissions, which can also have a secondary benefit of reducing the wave action that leads to accelerated erosion.

Biodiversity conservation and restoration

<u>Site selection and identification of no-go situations and areas in the lagoon</u>:

- focusing on areas where the impacts of blue economy sectors would lead to an unacceptable loss of biodiversity and/or ecosystem: the area around the Nador touristic resort, the urban zones (Nador, Beni Ansar and Kariat Arkman) and agricultural uses around the Marchica lagoon;

- using a system of prioritization based on biodiversity values and standards bodies for the lagoon’s confined areas (mainly Beni Ansar and Kalaat Arkman zones), thus ensuring that the established and on-going policies respond to the lagoon’s local conditions;

- adopting prioritization approaches based on the natural and specified habitat types and vulnerability. This includes: Key Biodiversity Areas (KBAs) and their subsets, such as the Alliance for Zero Extinction (AZE) sites; and High Conservation Value (HCV) areas, which are based on both social and biodiversity values;

- identifying areas with low biodiversity richness and biodiversity-based ecosystem services in the lagoon, which can be more appropriate for touristic development and other economic activities.

<u>Minimization of habitat disturbance and degradation</u>:

- assessing biodiversity values that may be impacted by the operations of different activities in the lagoon, such as infrastructure development and destructive methods for harvesting fish and plants. This can be supported by the prioritization approaches mentioned above;

- deploying impact mitigation techniques for specific operations such as water treatment protocols, distance barriers, and non-destructive sampling methods, among others.

Habitat restoration and connectivity. Assessing the land's and lagoon's current, previous and alternative surroundings according to their type of area and prioritizing the use of native species for restoration, based on clear guidance from accepted restoration practices.

Energy. Setting up an economic model for replacing non-renewable power sources with renewable resources in the agriculture and power utility sectors. Decreasing dependence on coal-fired power plants and studying alternatives for distributed generation based on available renewable sources. Setting up a solar power system that is used mainly for powering water treatment plants. Setting up policies that prevent building offshore power plants, which can harm marine life, especially in natural reserves like lagoons.

Fisheries. Impacts on fisheries generally stem from land-based impacts, namely agriculture and energy production. For this reason, the spillover effect from recommendations to other sectors will eventually reach the fisheries: wastewater purification, coastal wetland restoration and delimiting conservation areas. These will all serve the ecosystem, thus rendering the fisheries sector more viable.

Conclusions and perspectives. The Marchica lagoon is one of the coastal areas that is directly impacted by climate change due to its location. It is surrounded by important urbanization (Nador and Melilla cities), industrial activities, agriculture, tourism, and marine transportation. These intense activities affect the water quality in the lagoon. In this sense, policies have been implemented and studies were established to protect the area and its resources. The projected climate variability in the region over the next decades shows remarkable changes in weather, coastal hazards, water scarcity and wildfire. Therefore, this paper has offered some policy recommendations together with a suggested adaptation and mitigation model, all of which the government may apply to the different blue economy sectors studied here, thus sustaining the dynamics of the lagoon's ecosystem in order to overcome the region's forecasted climate change impacts.

Conflict of interest. The authors declare that there is no conflict of interest.

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Authors:
Chaymae Boujnan, Department of Earth Sciences, Faculty of Sciences and Techniques, University Abdelmalek Essaadi, Old Airport Road, Km 10, Ziaten. BP : 416, Tangier, Morocco, e-mail: chaymaeboujnan88@gmail.com
Bouchta El-Moumni, Department of Earth Sciences, Faculty of Sciences and Techniques, University Abdelmalek Essaadi, Old Airport Road, Km 10, Ziaten. BP : 416, Tangier, Morocco, e-mail: bouchta.elmoumni@uae.ac.ma
Mimoun Bahkan, 2Multidisciplinary Faculty of Nador, University of Mohammed Premier, BP 300, 62700 Selouane, Nador, Morocco, e-mail: mimoungeorif@gmail.com
Mimoun Chourak, Industrial and Seismic Engineering Research Team, National School of Applied Sciences of Oujda, Mohamed 1st University, 60000 Oujda, Morocco, e-mail: mchourak00@gmail.com
Hajar Bouzaidi, Department of Earth Sciences, Faculty of Sciences and Techniques, University Abdelmalek Essaadi, Old Airport Road, Km 10, Ziaten. BP : 416, Tangier, Morocco, e-mail: bouzaidi.hajar@gmail.com
Asmae Aknaf, Multidisciplinary Faculty of Nador, University of Mohammed Premier, BP 300, 62700 Selouane, Nador, Morocco, e-mail: asmae_facul@hotmail.fr
Adil Jouamaa, Industrial and Seismic Engineering Research Team, National School of Applied Sciences of Oujda, Mohamed 1st University, 60000 Oujda, Morocco, e-mail: adil.jouamaa@gmail.com
Meryam Mostakim, Department of Earth Sciences, Faculty of Sciences and Techniques, University Abdelmalek Essaadi, Old Airport Road, Km 10, Ziaten. BP : 416, Tangier, Morocco, e-mail: moustmeryem@gmail.com

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