Vulnerability and adaptative capacity assessment of the Moroccan coastal zone to the future sea level rise

SNOUSSI M., KHOUAKHI A., NIAZI S., and RAJI O
University Mohammed V-Agdal, Faculty of Sciences, Department of Earth Sciences
Research Group in Coastal Environment and Climate Change
Avenue Ibn Battota, B.P. 1014, Rabat
Emails : snoussi@fsr.ac.ma, saidaniazi@hotmail.com, abdouu2005@gmail.com, otmaneraji@gmail.com
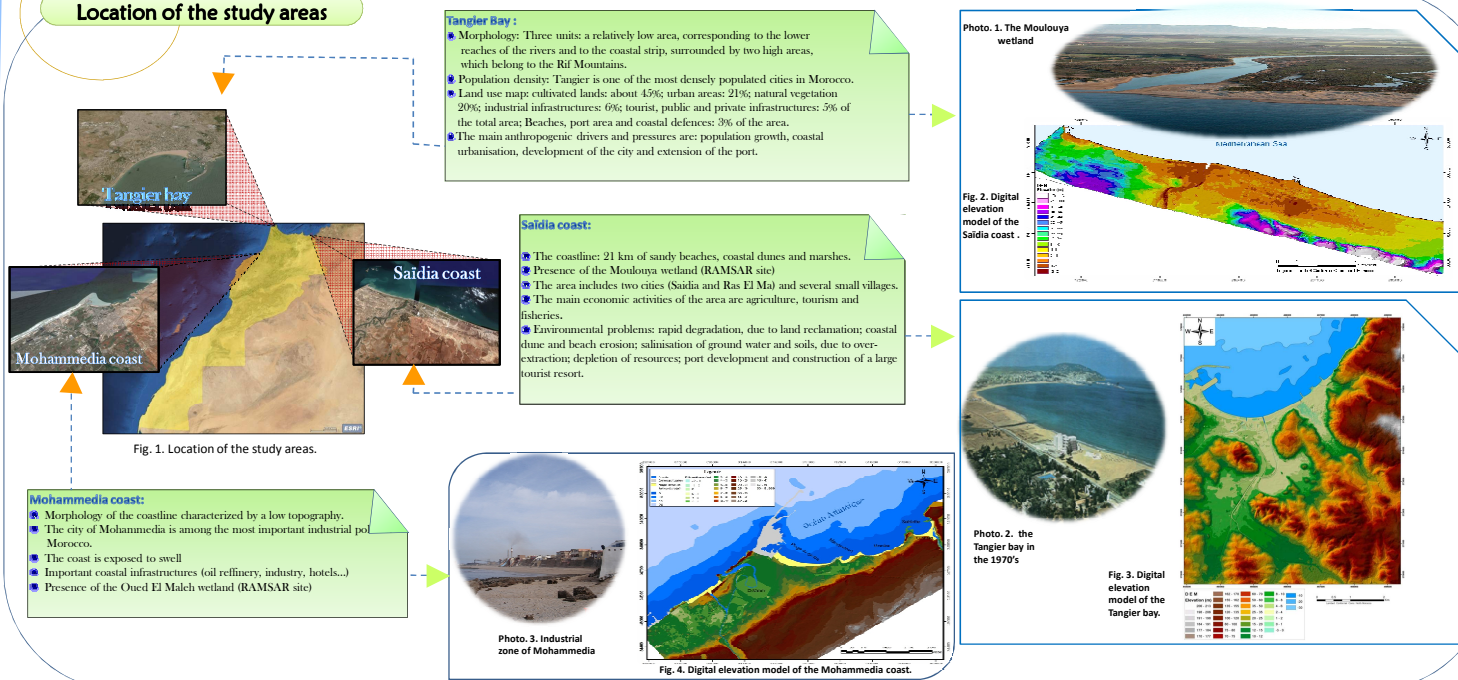
Abstract

The coast of Morocco is, in many locations, physically and socio-economically vulnerable to accelerated sea-level rise, due to its low topography and its high ecological, economic and touristic values. Assessment of the potential land loss by inundation and erosion, based on a modeling approach and Geographical Information Systems, has enabled to identify both locations and the socioeconomic sectors that are most at risk to accelerated sea-level rise and extreme events. The case studies of Saidia littoral (sandy beach with important RAMSAR site and high touristic value) on the Mediterranean coast, and Tangier and Mohammedia coasts (very populated and high economic value coasts) on the Atlantic side, show that the most severely impacted sectors, are expected to be the settlements, the recreational and industrial areas, agricultural land, and the natural ecosystems. Indeed, the conversion of natural coastal habitats such as coastal dunes and wetlands for urban or agricultural uses reduces the ability of such ecosystems to provide a natural barrier or buffer against wave action and storm surges, which results in further and increased erosion and flooding. This should be exacerbated with the expected rise in sea level.
Potential adaptation strategies to cope with the adverse effects of sea-level rise were analyzed. They include: wetland preservation; beach nourishment at tourist resorts; and the reforestation of dunes. In the medium term, an ICZM plan must be adopted to include building regulation, urban growth planning, development of institutional capacity, and increasing public awareness.
The study also identifies a number of barriers to adaptation, including physical, ecological, financial, institutional and technological barriers. In addition, it highlighted the fact that there are significant knowledge gaps for adaptation as well as impediments to flows of knowledge and information relevant to adaptation decisions.

Location of the study areas

Tangier Bay :
- Morphology: Three units: a relatively low area, corresponding to the lower reaches of the rivers and to the coastal strip, surrounded by two high areas, which belong to the Rif Mountains.
- Population density: Tangier is one of the most densely populated cities in Morocco.
- Land use map: cultivated lands: about 45%; urban areas: 21%; natural vegetation 20%; industrial infrastructures: 6%; tourist, public and private infrastructures: 5% of the total area; Beaches, port area and coastal defences: 3% of the area.
- The main anthropogenic drivers and pressures are: population growth, coastal urbanisation, development of the city and extension of the port.

Saïdia coast:
- The coastline: 21 km of sandy beaches, coastal dunes and marshes.
- Presence of the Moulouya wetland (RAMSAR site)
- The area includes two cities (Saidia and Ras El Ma) and several small villages.
- The main economic activities of the area are agriculture, tourism and fisheries.
- Environmental problems: rapid degradation, due to land reclamation; coastal dune and beach erosion; salinisation of ground water and soils, due to over-extraction; depletion of resources; port development and construction of a large tourist resort.

Mohammedia coast:
- Morphology of the coastline characterized by a low topography.
- The city of Mohammedia is among the most important industrial pol Morocco.
- The coast is exposed to swell
- Important coastal infrastructures (oil reffinery, industry, hotels...)
- Presence of the Oued El Maleh wetland (RAMSAR site)

Fig. 1. Location of the study areas.

Photo. 1. The Moulouya wetland

Fig. 2. Digital elevation model of the Saïdia coast .

Photo. 2. the Tangier bay in the 1970's

Fig. 3. Digital elevation model of the Tangier bay.

Photo. 3. Industrial zone of Mohammedia

Fig. 4. Digital elevation model of the Mohammedia coast.

Methodology

The methodology used to assess the vulnerability to sea level rise and adaptation of the area was based on the IPCC technical guidelines and on the UNEP Handbook 'coastal zones' chapter. The land loss due to coastal inundation was evaluated using a GIS-based inundation analysis. Projected flooded areas were calculated by using the Hoozemans et al. (1993) equation which defines the risk zone as the land area between the coastline and the design water level, taking into account the SLR as well as the flood risk associated with storm surges. To assess the socio-economic impacts on the areas, a typological classification of future inundated lands has been completed and mapped using the GIS environment.

Potential land losses due to inundation

Saïdia coast: inundation level: 2m

24% of the total area would be inundated, including 1) urban areas (30.4 %); 2) natural vegetation and agricultural lands (29%); and 3) beaches (7.4 %) and marshes (6.8%).
The results obtained indicate that the most vulnerable areas to inundation are the low-lying lands of the Moulouya delta and some parts of the coast, where natural coastal defences such as dunes have been destroyed. Urban settlements, including tourist resorts, would be the most
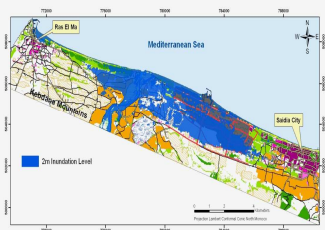
Fig. 5. Land area vulnerable to flooding With the minimum inundation level of 2m

Cartographic units	Inundation areas with the level of 2m
Urban areas	30.4%
Agricultural lands	14.2 %
Natural vegetation	14.8 %
Marshes	6.8 %
Beaches	7.4 %
Total	17.6 %

Table 2. Potential land loss by inundation for

Tangier Bay: inundation level: 4m

10% of the total area would be at risk of inundation, these lands being occupied mainly by 1) beaches, the artificial lake, the port and the coastal defences, which will be almost completely flooded, 2) tourist infrastructures along the coast and 3) the canal for water diversion.
The most vulnerable zones to inundation are the coastal defences and the port, in the urban area, the tourist coastal infrastructures, the railway, and the industrial area.

Cartographic Units	Inundated areas with the level
Roadways	8.0 %
Railways	0.5 %
beach	98.4 %
Shingle beach	95.8 %
Artificial lake	95.0 %
Canal for water diversion	49.4 %
Port	97.5 %
Coastal defenses	89.6 %
Urban area	14.9 %
Tourist infrastructures	69.1 %
Public & Private infrastructures	15.0 %
Industrial Zone	8.1 %
Land cover	2.9 %
Agricultural Area	6.3 %
Total area	9.65 %

Table 1 : Potential land loss by inundation for 4 m.
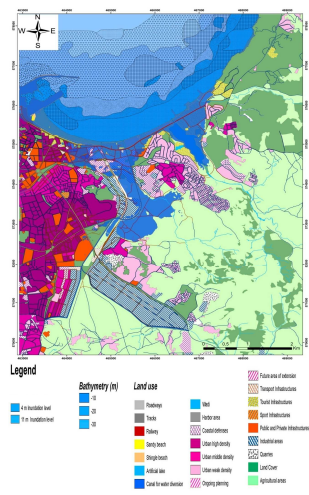
Fig. 6. Land area vulnerable to flooding With the minimum inundation level of 4m

Legend
Bathymetry (m) Land use

Mohammedia Coast : inundation level : 7m

With this inundation level the total flooded area would be approximately 28% of the total area of the study zone.
Figures 7 and 8 show the flooded surfaces of the various cartographic units identified in the land use map (fig.7). These floods would affect mainly the following units:
- Tourist units: the tourist zones already installed on the Mohammedia coast and those under construction would be almost (94.57%) flooded by 2050.
- The port of Mohammedia would be completely submerged, which will have a significant socio-economic impact, as the port is the cornerstone of the economy of the region.
- Industrial zones especially those located near the estuary of the Oued Al Maleh (SAMIR complex and thermal plant) present a major risk by 2050.
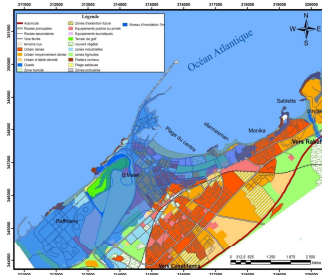The wetlands of Oued Al Maleh would be completely flooded due of its low topography.

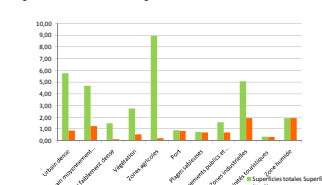Fig. 7. Land area at risk of flooding with the inundation level of 7m

Fig. 8. Potential land loss by inundation of 7 m.

In Tangier and Mohammedia coasts, the coastal stretches are so heavily controlled by human infrastructures that it is no longer possible for the beaches and the wetlands to re-adapt to any new conditions. In Saïdia coast, the conversion of natural coastal habitats such as the wetlands and the coastal dunes for urban or agricultural uses reduced the ability of such ecosystems to provide a natural barrier or buffer against wave action and storm surges, which will result in further and increased erosion and flooding with the expected rise in sea level.

Adaptation strategies

In spite of the large uncertainty regarding projected climate scenarios and empirical calculations, an anticipatory adaptation strategy must be developed. This should be based on a pro-active approach and 'no regrets' policy. However, it is clear that the vulnerability of the study areas to SLR will be mainly determined by the nature of ongoing development and the way the authorities manage its environment. Therefore, an integrated coastal zone management (ICZM) plan is the most appropriate and necessary tool for long-term sustainable development, which could tackle current and future vulnerabilities of the Moroccan coastal areas. This plan should actively involve the local communities, and include building regulation, urban growth planning, building institutional capacity and raising awareness. Such plan should deal with both SLR and other impacts of climate change and/or human activities, and ensure that coastal development does not increase the vulnerability of the region.
In the short-term, the most suitable range or mixes of options that are recommended for the study areas include: Beach nourishment, including building artificial dunes as storm buffers and beach sand reservoirs; hard structures such as groins and breakwaters could be used to reduce the wave energy and trap sand in the eroded parts of the coast. Building of sea walls is a high cost option; it would be used only for settlements and industrial areas of high value and at direct risk of inundation.
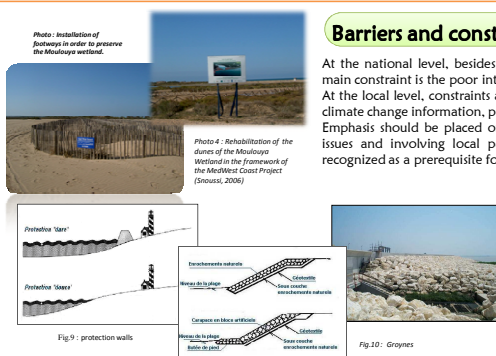
Photo : installation of footways in order to preserve the Moulouya wetland.

Photo 4 : Rehabilitation of the dunes of the Moulouya Wetland in the framework of the MedWest Coast Project (Snoussi, 2006)

Fig.9 : protection walls

Fig.10 : Groynes

Barriers and constraints to adaptation

At the national level, besides inadequate coordinating mechanisms at the institutional level, the main constraint is the poor integration of climate change issues in national policies and programs. At the local level, constraints are related to the level of education, access to and understanding of climate change information, poverty and cultural barriers.
Emphasis should be placed on increasing the awareness level of populations on climate change issues and involving local people directly in natural resource management, which has been recognized as a prerequisite for ecosystem conservation to be effective.