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A Geospatial approach for assessing the impacts of sea-level rise and flooding on the Kenitra coast (Morocco)

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Abstract

Under climate change, sea-level rise and increasing storm surge intensity will increase the likelihood of floods for coastal communities. The topography of the beach, the type of geological material and the level of human intervention will determine the extent of the area to be flooded and the rate at which the shoreline will move inland. The Kenitra coast is socio-economically vulnerable to accelerated sea-level rise, due to its low topography and its high ecological and touristic value. Therefore, coastal flood vulnerability assessments are necessary to inform decision making for coastal management, where applicable. A Geographic Information Systems (GIS) tool is commonly employed for these evaluations. In this paper, an inundation analysis, based on GIS tool has identified on 7 landareas and the socio-economic sectors that are most at risk to accelerated sea-level rise at Kenitra coast. The topography is generally low-lying. Results indicate that 20% and 50% of the area will be lost by flooding at minimum and maximum inundation levels, respectively. The most severely impacted sectors are expected to be the coastal defences and the port, the urban area, tourist coastal infrastructures, and the natural ecosystem. Such results may help decision makers during planning to take proper adaptive measures for reducing the Kenitra coast vulnerability, as well as increasing the resilience to potential future floods.

1. Introduction

Currently, it is emphasized that climate change, sea level rise, droughts and coastal zone flooding, tropical cyclones and storm surges will impact seriously upon the natural environment and human society in the coastal zones. In addition, increases in sea surface temperatures cause thermal expansion, which increases the water level of the sea surface [1], and as a result, the shoreline moves farther inland [2]. The warming of the atmosphere causes melting of mountain glaciers and polar ice sheets, thus increasing the rise in sea-level [2]. Regarding, in the Atlantic and the Mediterranean provinces, such changes in sea-level are significant in the context of development and population growth [3]. The coastal zone in Morocco extends for nearly 3500 km, along the Mediterranean Sea and Atlantic Ocean. This zone forms one of the main socio-economic areas of the country with more than 60% of the population inhabiting the coastal cities, as well as incorporating 90% of the industry [4]. Furthermore, beaches and coastal resorts constitute a large percentage of the Gross Domestic Product (GDP). However, due to diverse human pressures, many coastal areas are already experiencing acute environmental problems, such as coastal erosion, pollution, degradation of dunes, and salt-intrusion of coastal aquifers and rivers [5]. Accelerated sea level rise will intensify the stress on these areas, causing flooding of coastal lowlands, erosion of sandy beaches, and destruction of coastal wetlands. Therefore, sea-level rise has to be one of the main impacts of climate change on Northeast Morocco. The low topography of the areas makes it very vulnerable to sea-level.

The main objectives of this contribution are: (1)to determine zones at risk of flooding (2)to assess the most vulnerable socio-economic sectors at risk, and (3)to identify the most appropriate response options for the areas at risk to the Kenitra coast.

2. Study area description

The Kenitra coastline (20 km long) is located on the Atlantic Moroccan coast (Figure 1).It is a straight wave-dominated meso-tidal beach environment aligned about 30° to the N-S direction [4]. This coast delimits the Atlantic continental shelf and the subsiding Gharb plain located at the junction between the stable Meseta domain to the south and the Rifian domain to the north. The sandy beaches are mostly bordered by 5-20 m-high consolidated eolian dunes with the sediment consisting of medium sand ranging between 200 and 370 m [6] and a gentle foreshore slope of 1-3% [4]. Beaches are interrupted by the Sebou tidal inlet formed by two walls that extend approximately 600 m seaward from the low tide level shoreline [4]. The Sebou is the largest Moroccan river, draining approximately 40.000 km^2, stretching about 614 km from its source in the middle Atlas Mountains to the Atlantic Ocean, which represents 6% of Morocco's total land area [7-9].

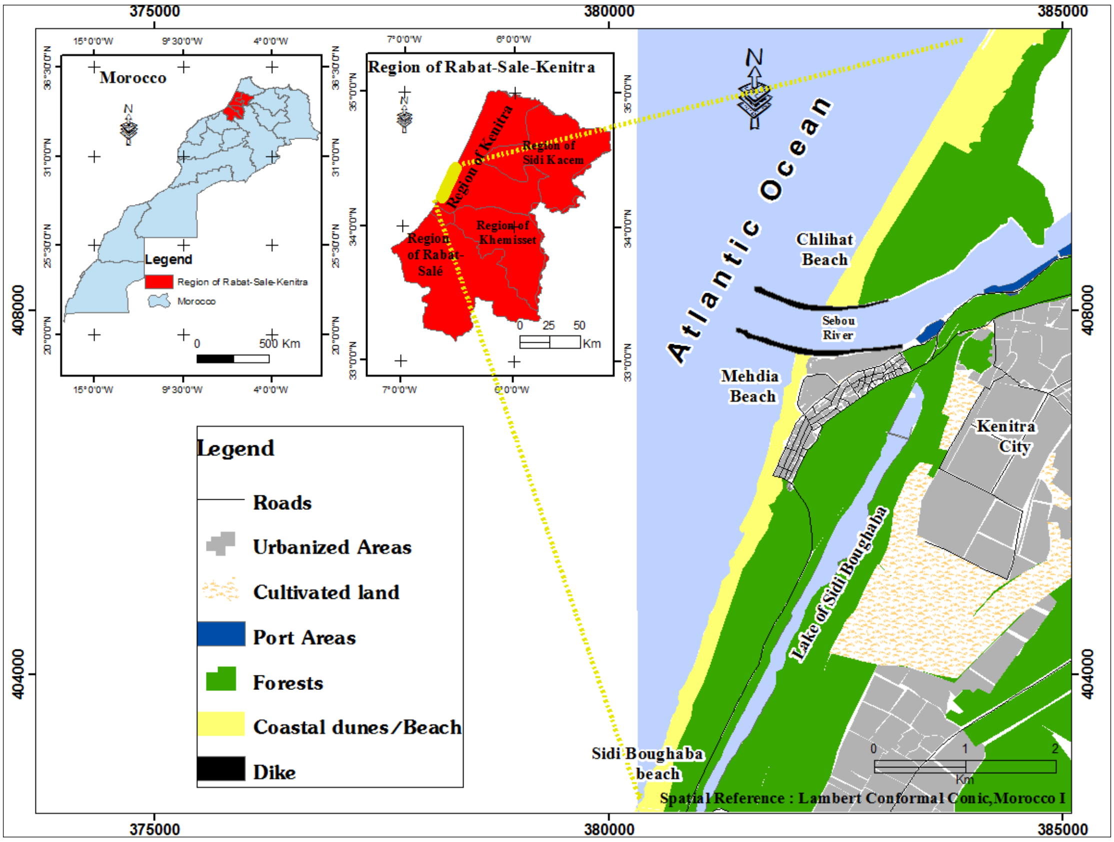


Figure 1 : Map of Kenitra coste showing the location of the study area

In this study three beaches, was investigated (i.e., Sidi Boughaba, Mehdia and Chlehat) (Figure 1). Thesebeaches an overall length of 20 km, are situated between 34°10' and 34°25' of Northern latitude.

In this coast the population growth has been rapid, from 367 551 to 832 770 inhabitants between 1971 and 2014 [10]. The industry, agriculture and fishing are the main economic activities in the region. In addition, this coast is planned to become one of the most developed tourist resort in Morocco, measures such as building regulation, urban growth planning and development of an Integrated Coastal Zone Management Plan and flood risk management, are recommended for the region.

3. Data and methods

In the process of assessing future risk of sea-level rise (SLR) and flooding in the Kenitra coast, scenarios must be selected. In many research papers generally used the year 2100, to set outer bounds of the global sea-level rise projections and time points in between. While the century time span provides a convenient long-term view on potential conditions, most applications demand scenarios that consider sea-level rise over more near-term periods of time, such as 25 or 50. In addition, the data of tidal and wave are necessary.

In the littoral zone, a Geographic Information System (GIS) is used to the homogenization and integration of all the available information into a Geo-database, in order to access data; cartography generated, and performs Global Digital Elevation Model Analysis (GDEMA). The Digital Elevation Model (DEM) is used to prepare the coastal elevation and to evaluate the spatial extent of future.

For Kenitra coast, the data elevation was extracted from restitutions maps of scales 1/5000 with equidistance's of 1m. The DEM (Figure 2) was generated from the interpolation of the elevation data by Triangular Irregular Network (TIN) and using Spatial Analyst and 3D analyst tool of ARC-GIS 10.3 of sea level analysis.

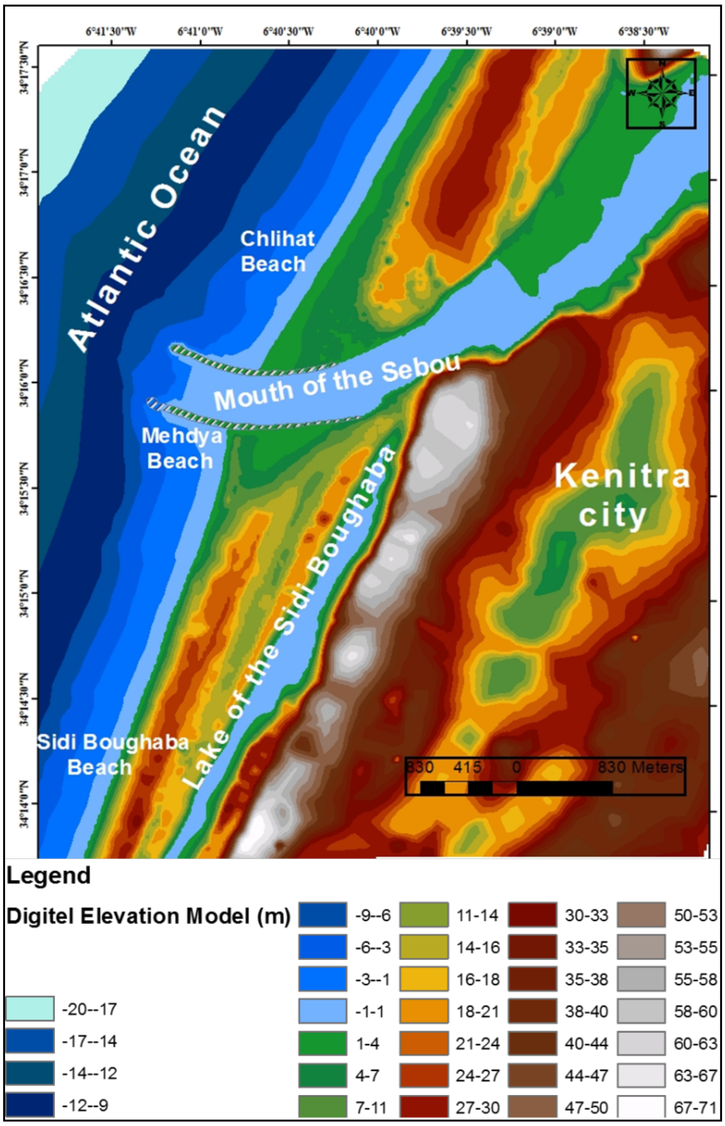


Figure 2 : Digital elevation model (DEM) of the study area

The GIS environment was used to classify and map the typology of land threatened by inundation (Figure 3).

3.1. Scenarios used

Future scenarios of sea level rise used in this study are based on the projections carried out by Warrick et al. [11]; they ranged from 0.20 to 0.86 m for the IS92a greenhouse gas emission scenario in 2100. This scenario assumed: (1) a level of emissions that would contribute to a doubling of carbon dioxide concentration in the atmosphere by the end of the 21st century; (2) a world population of 11.3 billion people by 2100, from population projections by the World Bank; and (3) an annual growth rate in gross national product (GNP) of 2.3% by 2100. However, as the long-term geological data suggested insignificant tectonic variations, the rise in global sea levels were considered a credible scenario.

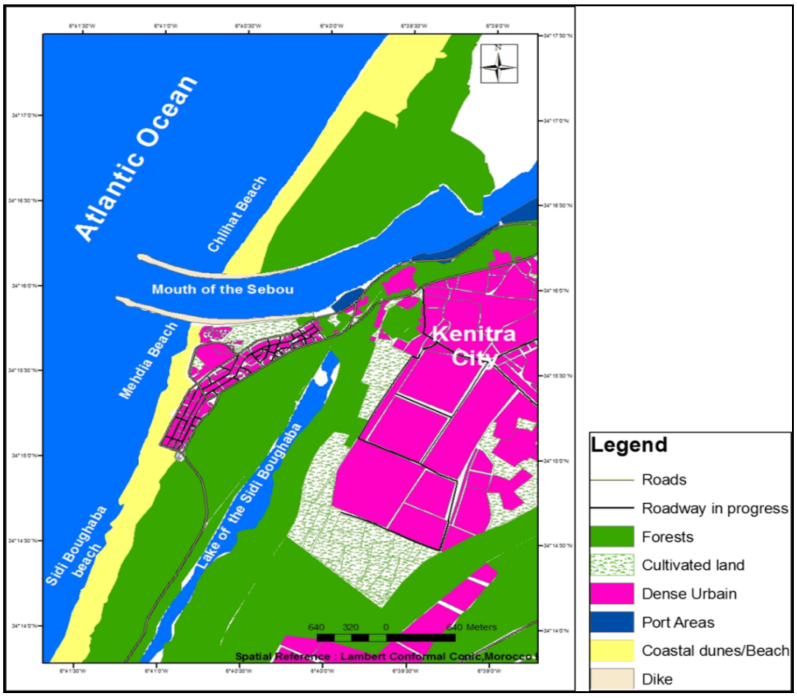


Figure 3 :The map Land-use of the study area

3.2. Inundation Scenarios

[12] Defined the risk zone as the land area between the coastline and the "maximum" design water level, which can be calculated from the equation (1):

$$In_{Lev}=M_{HW}+S+H_{TR}+SP \quad (1)$$

Where: In_{Lev} is the inundation level; M_{HW} the mean high water level; S is the relative sea-level rise; HTR the height of waves and SP the sea-level rise due to a lowering of the barometric pressure.

The nearest tide station to the study area was at Sebou mouth (34°16' N, 6°41'W), which has measurements available for this study; the database exploited for the analysis of the dynamics of the swell to broad and the shore of the sector of study was downloaded site of the NOAA. They are data of the model of total vagueness WW3, which calculates on a grid covering the whole of the sphere, with a resolution of 1° into North-South and of 1°15' in Is/Western, the physical parameters of the swell (significant Height, period of peak and angle of incidence). The point of grid nearest to Gharb, is at the point N34°00' 00 E7°15' 00, located at 32 km of the shore [13].

Two levels of inundation were considered:

The minimum inundation levels were calculated using a mean value of 0.83 m for the mean high water level, 3 m for mean wave heights, and a low estimate of 0.2 m for sea-level rise. For the maximum inundation levels were calculated using a mean value of 3.97 m for the mean high water level, a storm wave height of 8.5 m with a return period of 1 per 100 years, and a high estimate 0.86 m for sea-level rise. These values were related to the hydrographic zero. The values used to estimate the potential land loss by inundation were between 4 m and 13 m for minimum and maximum inundation levels, respectively.

3.3. Socio-economic impacts

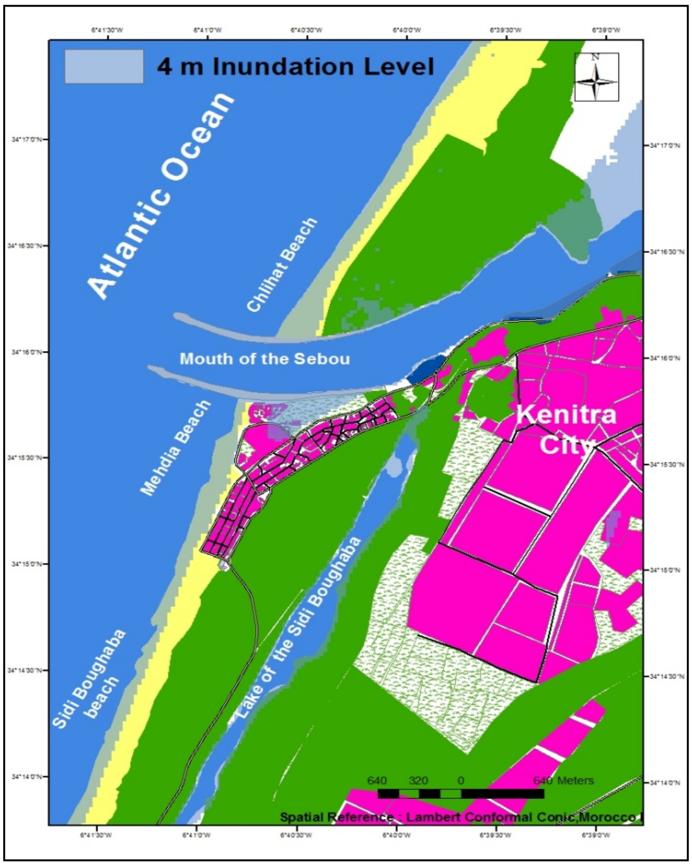
Having determined the land losses due to inundation, the impacts of the losses on the major socio-economic sectors (tourism, agriculture, urbanization) as well as natural ecosystems at risk were estimated by overlaying the land-use map and inundation levels map.

4.Results and discussion

Some is its rate; the sea-level rise would increase the level of waves attack, because a higher sea level would be providing a higher base for the powerful movements of the storms [14]. This would result in the flood of the low land and the changes in coastal morphology. Potential effect of such phenomenon does not depend on the rate of this rise, the frequency and the intensity of the swells of storms, but also of the sensitivity of the coast to the immersion, which in its turn depends on morphology and of the topography of the coastal area.

4.1. Land losses due to inundation

The main results of land loss due to inundation are presented in Figures 4 and 5. The most significant changes are the natural coastal defences, such as dunes, have been destroyed. At the minimum inundation level 4 m (Figure 4), 20% of the total area would be flooded including: Coastal dunes/beach, cultivated land, mouth of Sebou and Lake of the Sidi Boughaba.



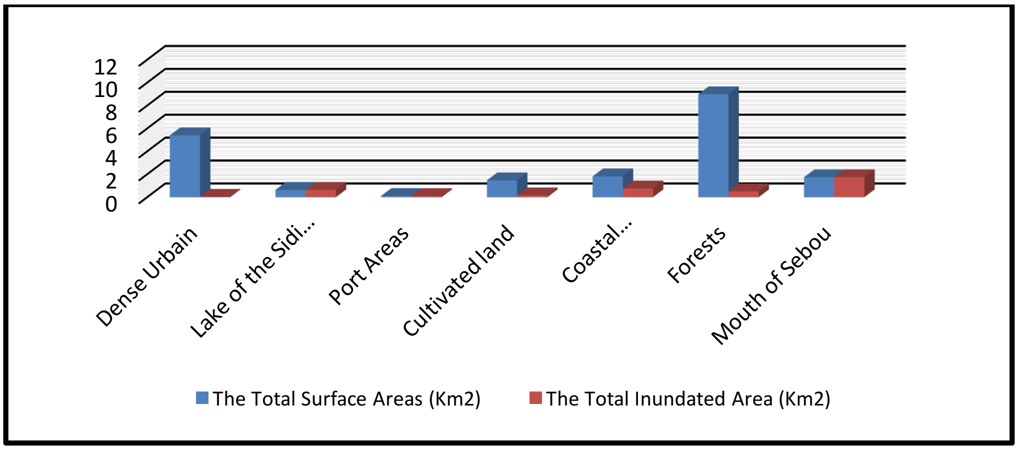


Figure 4 :Land area vulnerable to flooding with minimum inundation level of 4 m and results of the vulnerability assessment in 2100.

At the maximum inundation level 13 m (Figure 5), 50% of coastal land would be under direct risk of flooding including: Urban areas near the beach, the ports; the tourist resort of Mehdya; cultivated land; and coastal dune. Such a loss of land implies that the population living presently in these areas would be displaced. Even if some parts of the ecosystem of the Mehdya wet land are not destroyed, because those parts could adapt to sea-level-rise and move landwards, the species richness is likely to decrease, due to unfavourable new conditions where several plant communities and rare species would disappear. Indeed, potential loss of people living in the area at risk of flooding, as well as industrial infrastructures [15].

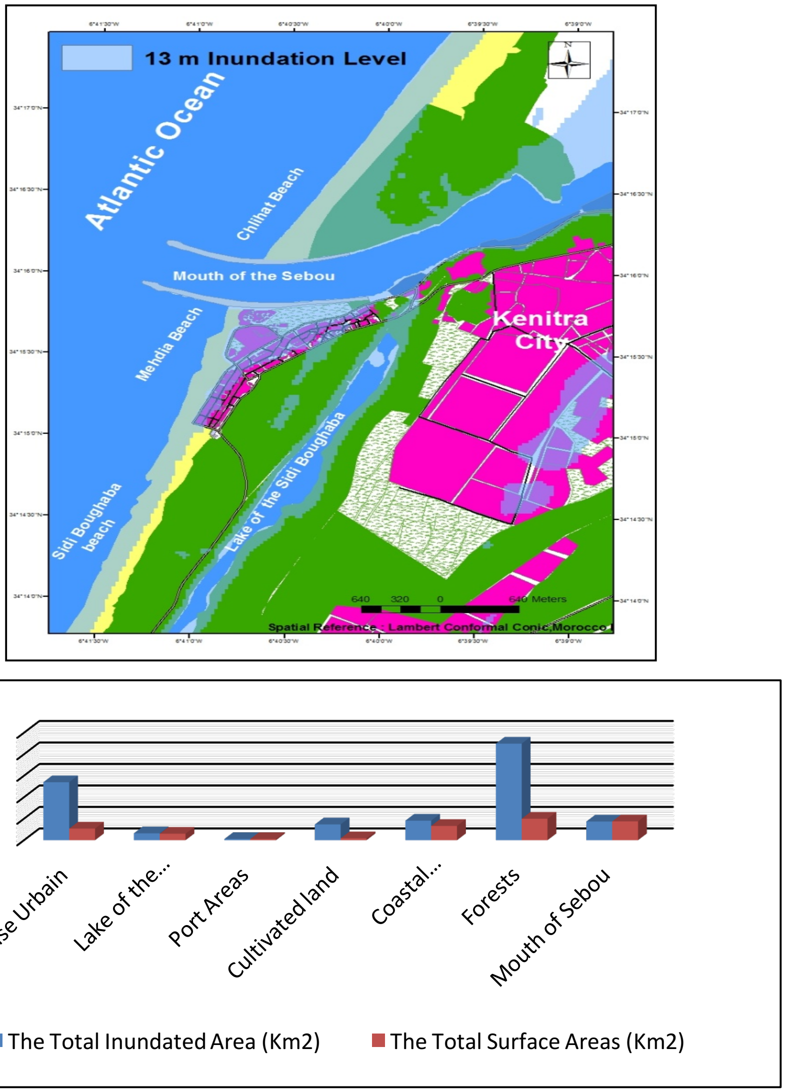


Figure 5 :Land area vulnerable to flooding with maximum inundation level of 13 m and results of the vulnerability assessment in 2100.

The main results of land loss due to inundation are presented in Figures 3, 4 and 5; the most significant changes are the natural coastal defenses, such as dunes, have been destroyed. At the minimum inundation level (3.87, 3.93 and 4.03 m); 20% of the total area would be flooded, including: Coastal dunes/beach, cultivated land, Mouth of the Sebou and Lake of the Sidi Boughaba (Table 1).

Table 1. Potential land loss of the main sectors for 3 m and 9 m inundation levels scenarios.

Areas (Km^2)		Minimum inundation level (3 m)	Maximum inundation level (9 m)
		%	%
Dense Urbain	5.40	0.50	3.00
Lake of the Sidi Boughaba	0.64	0.64	0.64
Port Areas	0.11	0.11	0.10
Cultivated land	1.47	0.70	0.65
Coastal dunes/Beach	1.82	0.80	1.60
Forests	8.99	1.50	2.50
Mouth of Sebou Estuary	1.74	1.74	1.74

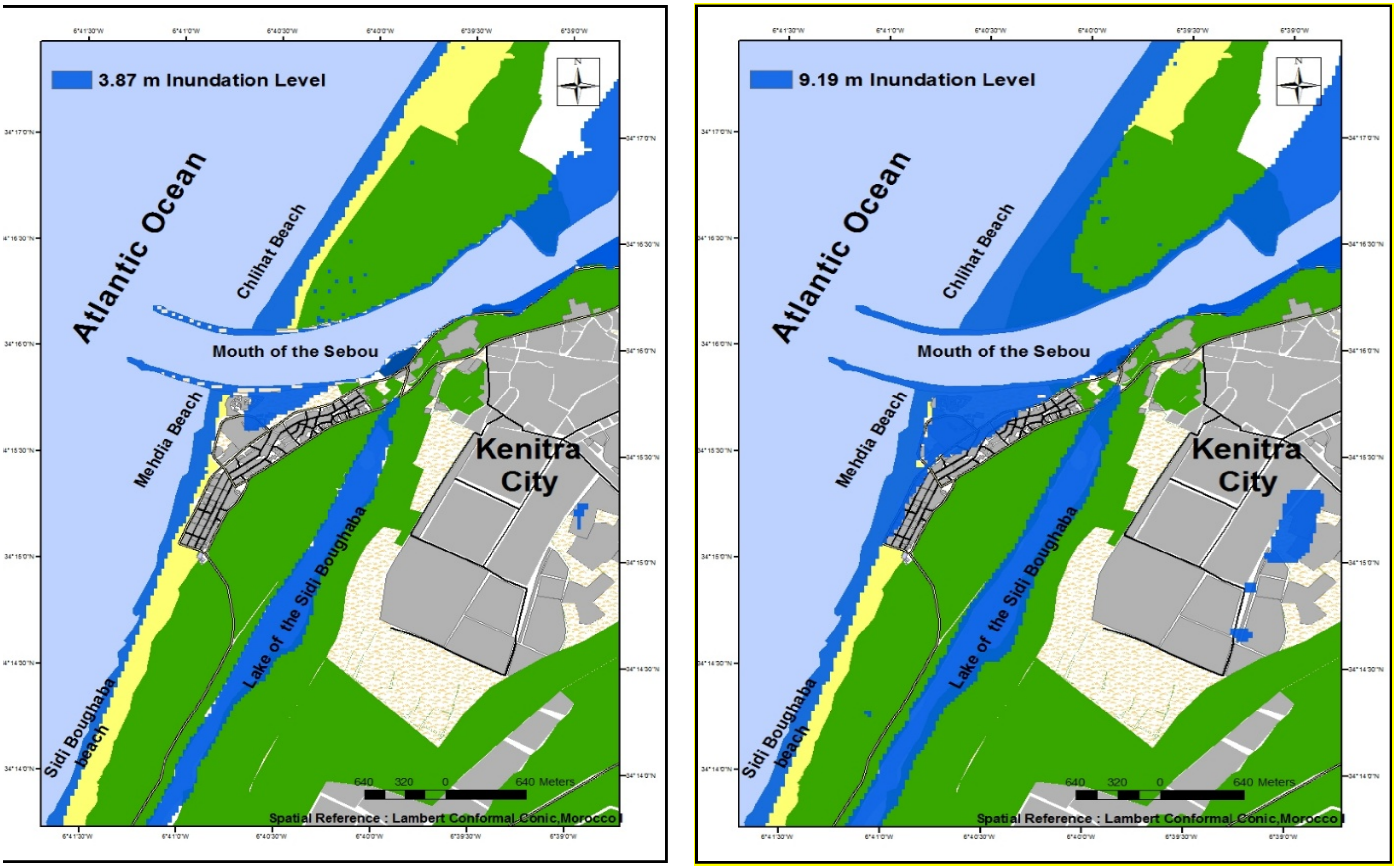


Figure 6. Land area vulnerable to flooding with the minimum inundation level (3.87 m), the maximum (9.19 m) and results of the vulnerability assessment in 2025.

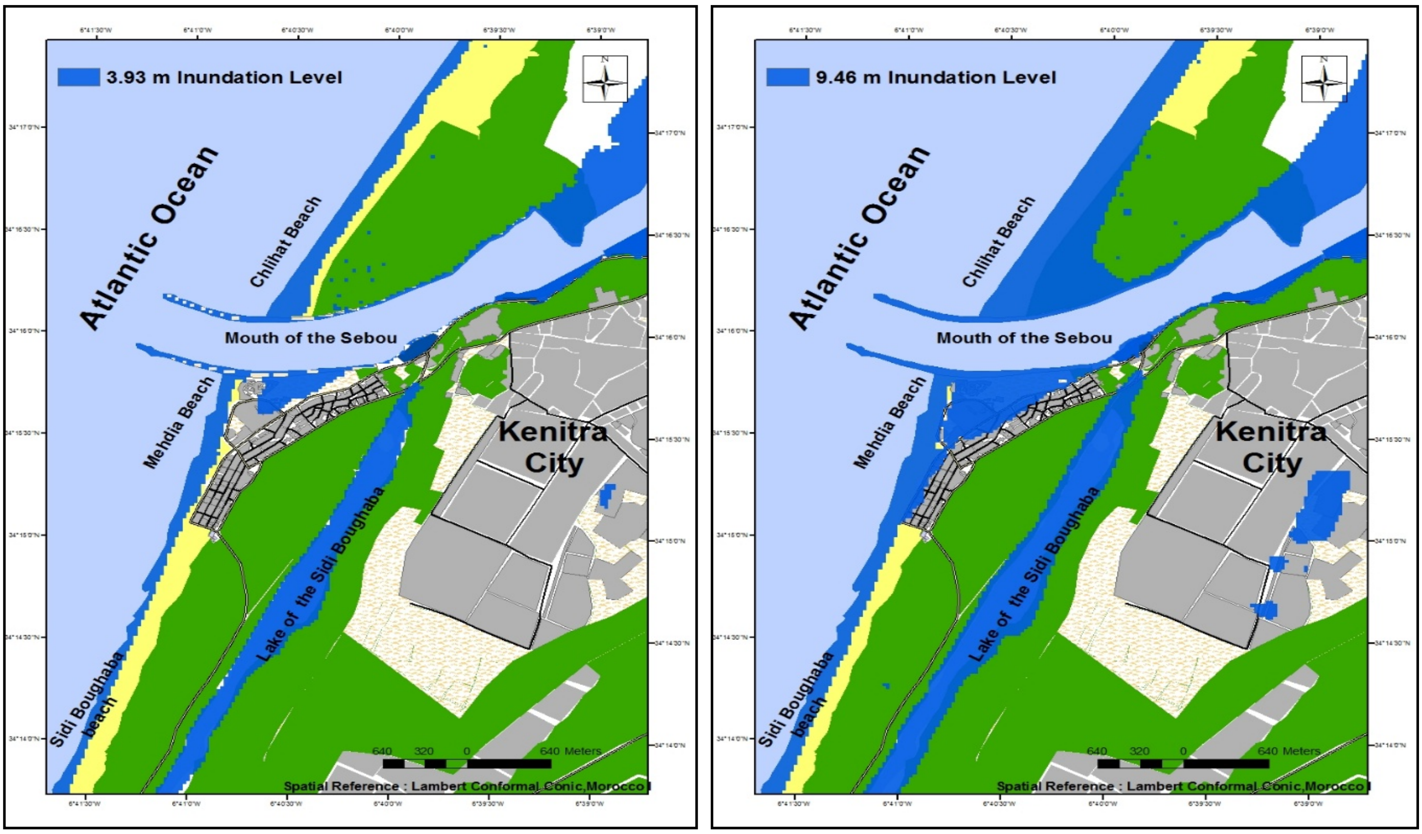


Figure 7. Land area vulnerable to flooding with the minimum inundation level (3.93m), the maximum (9.46 m) and results of the vulnerability assessment in 2050.

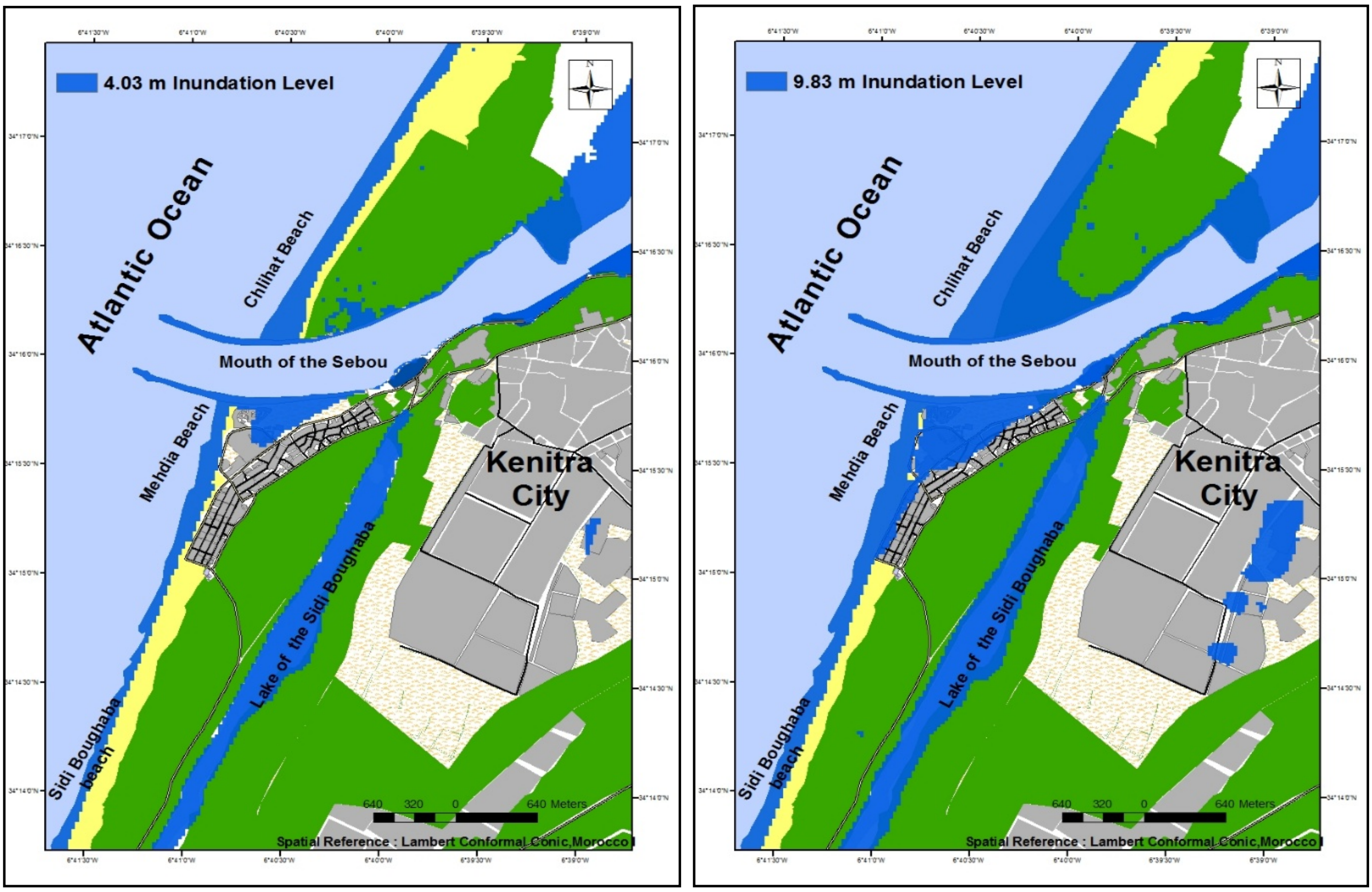


Figure 8. Land area vulnerable to flooding with the minimum inundation level (4.03m), the maximum (9.83m) and results of the vulnerability assessment in 2100.

4.2. Socio-economic impacts of sea-level rise

In Kenitra, the exposure of socio-economic stakes would be increasingly strong as the level of flood would be high. Coastal ecosystems would be flooded, particularly those occupying topographically low areas. Thus, Sebou River and Sidi Boughaba Lake are in danger of being completely flooded by 2100.

As for the Kenitra beaches, they would be moderately submerged, as rising sea levels will accelerate coastal erosion. Followed by tourism infrastructures located in Mehdya beach. The forest in Chlihat beach, would be low threatened by an accelerated rise in sea level.

4.3.Response strategies and adaptation

The rise in the sea level will have consequences on the environment but also on various sectors of the economy whose in particular tourism and will necessitate interventions (protection, rehabilitation…etc) who will not be always easy, nor even possible sometimes.

On the technical plan, the strategy of protection of littoral of Kenitra chooses to combine the following options:

- Artificial recharging sands some to rehabilitate the eroded beaches.
- The rehabilitation and the fixing of the dunes by the vegetation; and conservation of these dunes, because the dunes keep a big part of coastal sedimentary stocks, they play of the direct and indirect roles in protection against erosion and the immersion.
- The construction of walls of protection and/or reinforcement of the ripraps to protect the residential areas most exposed, in particular the dwellings, and the establishments' tourist and industrial;
- The progressive heightening of the peaks of the harbor dike.
- The strategies of answer to the climate changes could be effective only within the more total framework of a GIZC which represents a tool impossible to circumvent for the sustainable development of the Moroccan littorals.

For this purpose, the creation of an institution responsible for management and installation of the coastal areas, in an integrated and prospective vision, would be probably the best way of accompanying the processes of adjustment by the Moroccan coastal areas to cope with the future climate changes.
In addition, it is obvious that with the EANM, the maritime public domain any more the same configuration will not have, and its legal mode as stipulated in the current texts will have to be re-examined and modified. For this reason, it is more than wise that it is taken account in the law Littoral, still with the state of project, of the future rise in the sea level.

Conclusions

Sea level rise is a realistic approach with the coastline geometry. So, understanding the mechanisms of the sea-level change and its impacts on the coastal ecosystem has gained increasing importance of climate change. The projection of future sea-level rise and resulting coastal inundation is a crucial task in order to raise the awareness of people, to set up efficient coastal management programs, and to mitigate probable hazard risks. This study focuses on the projected inundation of Kenitra Coast, one of the most productive, but at the same time most susceptible to sea-level rise, areas of Morocco. The results obtained indicate that the most vulnerable areas to inundation are the low-lying lands of Kenitra where natural coastal defences such as dunes have been destroyed in Mehdya Beach. Urban settlements, including tourist resorts, the costal dunes and Beach, Mouth of the Sebou estuary, Sidi BoughabaLake would be the most affected economic sectors, followed by cultivated land and Forests. These results draw attention towards the importance of upgrading awareness of decision-makers and planners to the potential future impacts of sea-level rise on this region. However, to be more complete, this study should include other assessments. In particular, it is recommended that:

- The impact of sea-level rise on freshwater resources, including the saltwater intrusion and water logging problems should be considered.
- Vulnerability assessments should include detailed socioeconomic impacts, together with evaluation of the costs of these impacts and those of the adaptation measures.
- The stopping of the destruction the dunes and maintaining these unique environments and a share of freedom necessary for expressing their biodiversity help ensure the best role of "shock absorber" to climate change.

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