Available online at www.sciencedirect.com
ScienceDirect
Estuarine, Coastal and Shelf Science 77 (2008) 206–213
ESTUARINE COASTAL AND SHELF SCIENCE
www.elsevier.com/locate/ecss

Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: The case of the Mediterranean eastern zone

Maria Snoussi*, Tachfine Ouchani, Saïda Niazi

University Mohamed V, Faculty of Sciences, Department of Earth Sciences, Avenue Ibn Battota, BP 1014, Rabat, Morocco

Received 9 December 2006; accepted 17 September 2007
Available online 23 October 2007

Abstract

The eastern part of the Mediterranean coast of Morocco is physically and socio-economically vulnerable to accelerated sea-level rise, due to its low topography and its high ecological and touristic value. Assessment of the potential land loss by inundation has been based on empirical approaches using a minimum inundation level of 2 m and a maximum inundation level of 7 m, where scenarios for future sea-level rise range from 200 to 860 mm, with a 'best estimate' of 490 mm. The socio-economic impacts have been based on two possible alternative futures: (1) a 'worst-case' scenario, obtained by combining the 'economic development first' scenario with the maximum inundation level; and (2) a 'best-case' scenario, by combining the 'sustainability first' scenario with the minimum inundation level. Inundation analysis, based on Geographical Information Systems and a modelling approach to erosion, has identified both locations and the socioeconomic sectors that are most at risk to accelerated sea-level rise.

Results indicate that 24% and 59% 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 residential and recreational areas, agricultural land, and the natural ecosystem. Shoreline erosion will affect 50% and 70% of the total area in 2050 and 2100, respectively. Potential strategies to ameliorate the impact of seawater inundation include: wetland preservation; beach nourishment at tourist resorts; and the afforestation of dunes. As this coast is planned to become one of the most developed tourist resorts in Morocco by 2010, measures such as building regulation, urban growth planning and development of an Integrated Coastal Zone Management Plan, are recommended for the region.

Keywords: sea-level rise; Morocco; Mediterranean coastal zone; impacts assessment; adaptation

1. Introduction

Nowadays, it is recognised that climate change and sea level rise will impact seriously upon the natural environment and human society in the coastal zone. In Morocco, the coastal zone 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. 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 saline intrusion of coastal aquifers and rivers. 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 Morocco.

The eastern part of the Mediterranean coast of Morocco, between the Cape of Ras El Ma and Saïdia city (Fig. 1), comprises a long stretch of sandy coastline interrupted by the Moulouya delta; this, in turn, represents the most important wetland of the Mediterranean coast of Morocco. The low topography of the area makes it very vulnerable to sea-level

* Corresponding author.
E-mail address: snoussi@fsr.ac.ma (M. Snoussi).

0272-7714/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2007.09.024

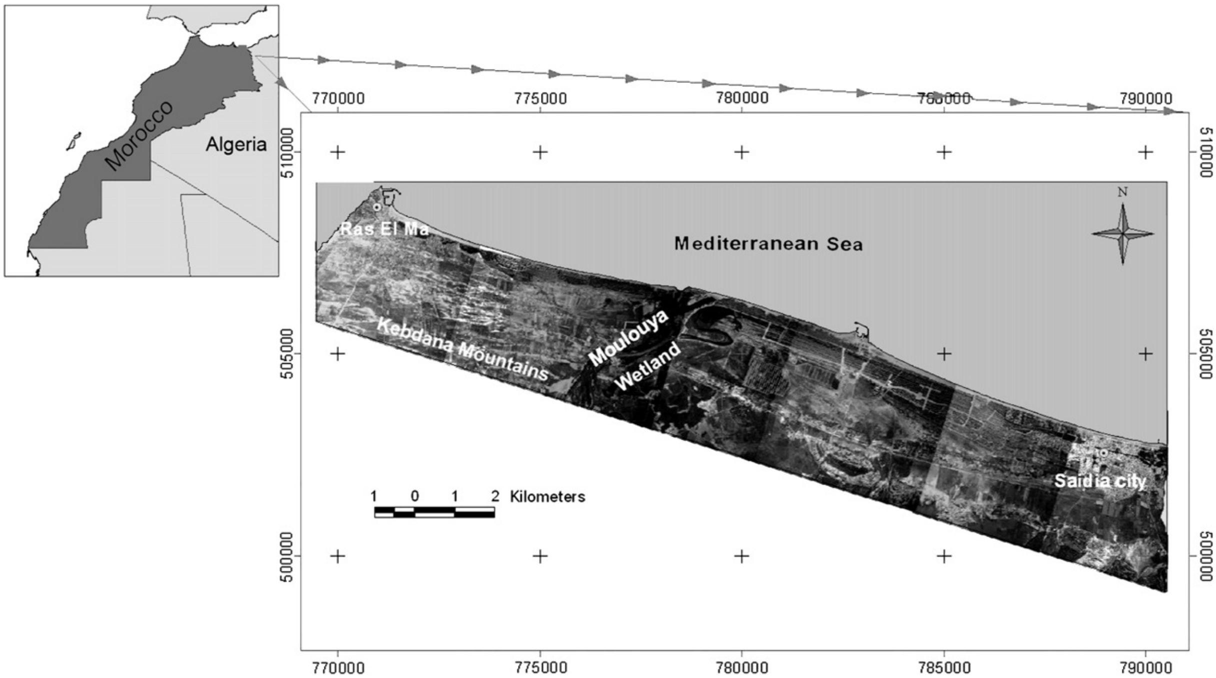

Fig. 1. Location of the study area.

rise. As part of a broad assessment of climate change impacts, the Moulouya coast has been the first coastal zone in Morocco where an assessment has been undertaken on vulnerability and adaptation to sea-level rise.

The main objectives of this contribution are: (1) to determine areas at risk from flooding and erosion; (2) to assess the most vulnerable sectors at risk; and (3) to identify the most reasonable options available to mitigate these risks to the Saïdia coast.

2. Description of the study area

The study area is located in the easternmost part of the Mediterranean coast of Morocco (Fig. 1). The coastline (21 km) is straight and indented only by the Moulouya estuary mouth which, with its marsh complex, represents a site of biological and ecological interest of about 3000 hectares (Fig. 2). This wetland is a refuge for many birds of national and international interest, as well as the habitat for an exceptional and diversified fauna and flora (Dakki, 2003). The main objective of the MedWetCoast project (http://www.medwet-coast.com), which includes the Moulouya wetland, is the conservation of these coastal ecosystems. Indeed, action has already being undertaken to protect this wetland, such as the restoration of the dunes, the management of the traffic within the wetland and the promotion of public awareness.

The primary shore type of the area is sandy beaches, with coastal dunes and marshes. The area includes two cities (Saidia and Ras El Ma in Fig. 1) and several small villages. Today, almost 42,700 people reside permanently in the area (RGPH, 2004); whilst in Saïdia alone the influx of tourists can reach 15,000 per day during the summer months. The main economic activities of the area are fisheries, agriculture and tourism. Although fisheries have been declining over the last two decades, fishermen have been converting to agriculture which has also become increasingly vulnerable as farmland is abandoned or converted to other uses, due to the recurrent droughts and the high salinisation of the soils (Khattabi, 2002); only tourism has been expanding rapidly over recent decades.

Like other coastal zones, the area has suffered from several human activities over the past 20 years. Although the human population is relatively small, development along the coast is extensive and is still expanding. The main threats and environmental problems are rapid degradation: due to land reclamation; coastal dune and beach erosion; salinisation of groundwater and soils, due to over-extraction; depletion of resources through hunting, overgrazing, and wood cutting; and port development. At present, the largest human impact on the region is from tourism development; this will increase as the Saïdia coast is scheduled by 2010 to become one of Morocco's premier tourist resorts. The planned project will cover an area of about 700 hectares (Fig. 2), encompassing residential houses and flats, eight hotels, three golf courses, numerous green parks, and a pleasure port.

All these stresses have reduced, and will continue to reduce, the natural and socio-economic capacity of the coast to adapt to change, thereby, increasing the vulnerability to future sea-level rise.

The Moulouya wetland is a fragile coastal environment subject to continuous morphological changes in response to both natural and anthropogenic factors. The coastline evolution around the delta has been investigated by different authors (Zourarah, 1994; Zarki, 1999; Irzi, 2002; Boumeaza, 2002;

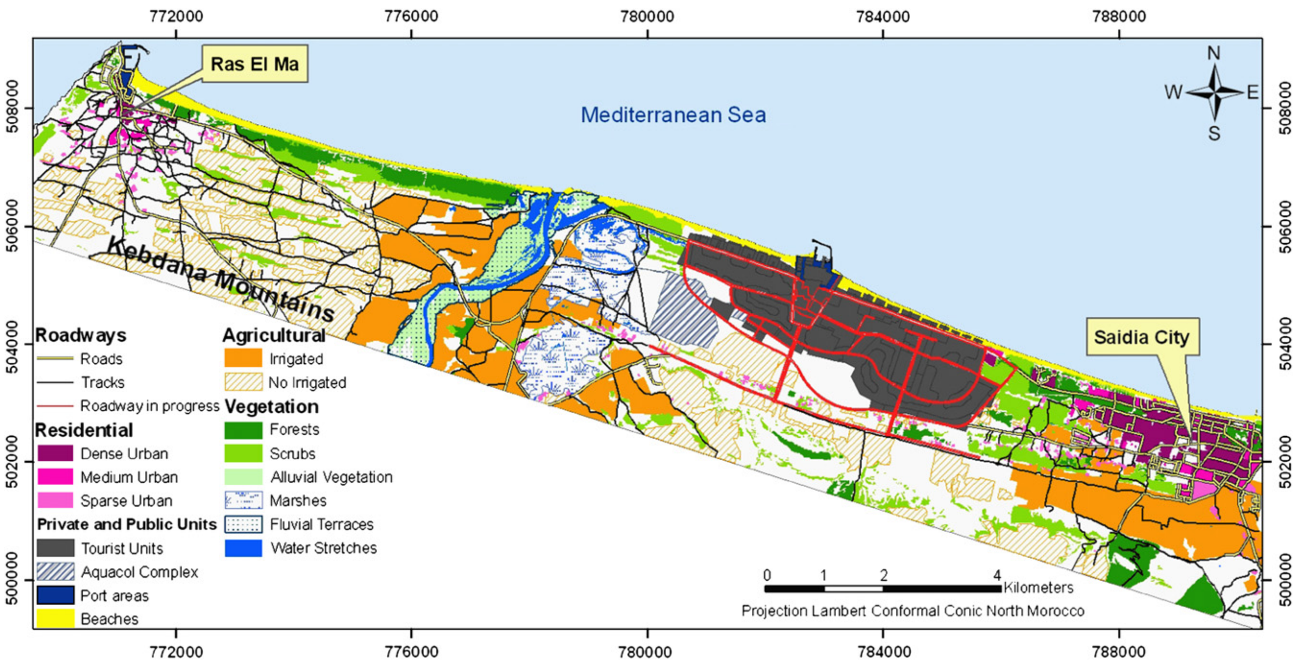

Fig. 2. Land-use map of the study area. For interpretation of the references to color in the text, the reader is referred to the web version of this article.

Imassi and Snoussi, 2003), using time-series of aerial photographs, for different years since 1958. According to Boumeaza (2002), the delta has retreated by 13 m year^{-1} between 1958 and 2001. Imassi and Snoussi (2003) have estimated that the mouth of the delta has lost more than 80 hectares between 1958 and 1986. This retreat is attributable to the drastic reduction in water and sediment discharges from the Moulouya River, following the construction in 1967 of the Mohamed V dam (Snoussi et al., 2002). Previously, the high sediment discharge of the Moulouya has limited the damaging effect of currents and waves, on the beach material. Presently, the increasing marine influence promotes sediment erosion which, in combination with sea-level rise and higher storm surges, will cause serious damage to the Moulouya wetland, as well as to other locations along the Saidia coast.

3. Methodology

The methodology used to assess the vulnerability and adaptation of the area to sea-level rise was based upon the Intergovernmental Panel on Climate Change (IPCC) technical guidelines (Carter et al., 1994) and on the Coastal Zone chapter of the handbook of the United Nations Environmental Programme on methods for assessment of climate change (Klein and Nicholls, 1998). Land loss, due to coastal erosion and coastal inundation, were the two types of physical impacts considered in this study.

3.1. Sea level scenarios

Over the last century, global sea level change was estimated typically from tide gauge measurements on the basis of long-term averaging. Since long-term measurements were not available for Morocco, data was used from satellite altimeters (Topex/Poseidon, since 1992; Jason, since 2001) to estimate the global mean sea level over the Mediterranean, i.e. nearly 3 mm year^{-1} for the period 1993–2004.

The estimates for future sea-level rise used in this paper (Table 1) were those presented by Warrick et al. (1996); they ranged from 200 to 860 mm for the IS92a greenhouse-gas emission scenario in 2100, with a 'best estimate' of 490 mm. According to the IPCC, 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. Data on land movements (subsidence/uplift) were not available for the study area. However, as the long-term geological data suggested insignificant tectonic variations, the rise in global sea levels were considered a credible scenario.

3.2. Coastal topography and land use

An initial requirement for the analysis of flooding impacts was the development of spatial datasets. Elevation data were extracted from stereoscopic pairs of 1:10,000 aerial photographs (of 2004), using a photogrammetric process. A digital

Table 1
IPCC scenarios for sea-level rise (Warrick et al., 1996)

Scenarios	Sea-level rise (cm)	
	2050	2100
Low (no acceleration)	7	20
Best	20	49
High	39	86

elevation model (DEM) was generated from the interpolation of the elevation data by triangular irregular network (TIN), and a database of ground control points (GCPs) measured by a ground positioning system. This was undertaken using the Arc Geographical Information System (GIS) software. The horizontal resolution of the DEM was 2 m, which accurately represented narrow features such as roads and dunes; the vertical accuracy was 0.5 m. The GIS environment was used to classify and map the typology of land threatened by inundation.

3.3. Inundation level scenarios

Empirical approaches were used to assess the inundation levels, using the Hoozemans et al. (1993) equation:

$$\mathrm{Dft} = \mathrm{MHW} + \mathrm{St} + \mathrm{Wf} + \mathrm{Pf} \quad (1)$$

where Dft is the inundation level, MHW the mean high water level, St the relative sea-level rise, Wf the height of storm waves and Pf the sea-level rise, due to a lowering of the atmospheric pressure.

The nearest tide gauge to the study area was at Malaga (36°71′0 N, 4°41′0 W), which had measurements available for the current study since 1992; data on sea-level variations included astronomical as well as meteorological elevations. Data on swells, waves and storm surges were obtained from Spanish stations based near Melilia (http://www.puertos.es) and from the Environmental Impact Assessment (EIA) report on the implementation of the Mediterranean Saïdia resort (Idom, 2004).

The minimum inundation levels were calculated using a mean value of 0.6 m for mean high water (MHW), 2.17 m for mean wave heights, and a low estimate of 0.07 m for sea-level rise. The maximum inundation levels were calculated using a mean value of 0.96 m for MHW, a storm wave height of 6.20 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, which was 0.70 m below the general datum in Morocco. The results are presented in Table 2.

Table 2
Minimum and maximum inundation levels, in 2050 and 2100 (CC, climate change; SLR, sea-level rise)

Scenarios	Minimum inundation levels (m)		Maximum inundation levels (m)	
	Without CC	With SLR low hypothesis	Without CC	With SLR high hypothesis
2050	2.24	2.31	6.29	6.83
2100	2.51	2.71	6.78	7.64

The values used to estimate the potential land loss by inundation were between 2 m and 7 m for minimum and maximum inundation levels, respectively.

3.4. Coastal erosion assessment

As the study area was mainly sandy, the Bruun rule (Eq. (2)) was used to predict coastal retreat due to sea level rise (Bruun, 1962, 1988):

$$R = SGL/(b + h) \quad (2)$$

where R is the retreat due to sea-level rise, S is the sea-level rise, G is the proportion of eroded material which remains in the active profile, L is the active profile width, b is the dune height, and h is the depth of closure.

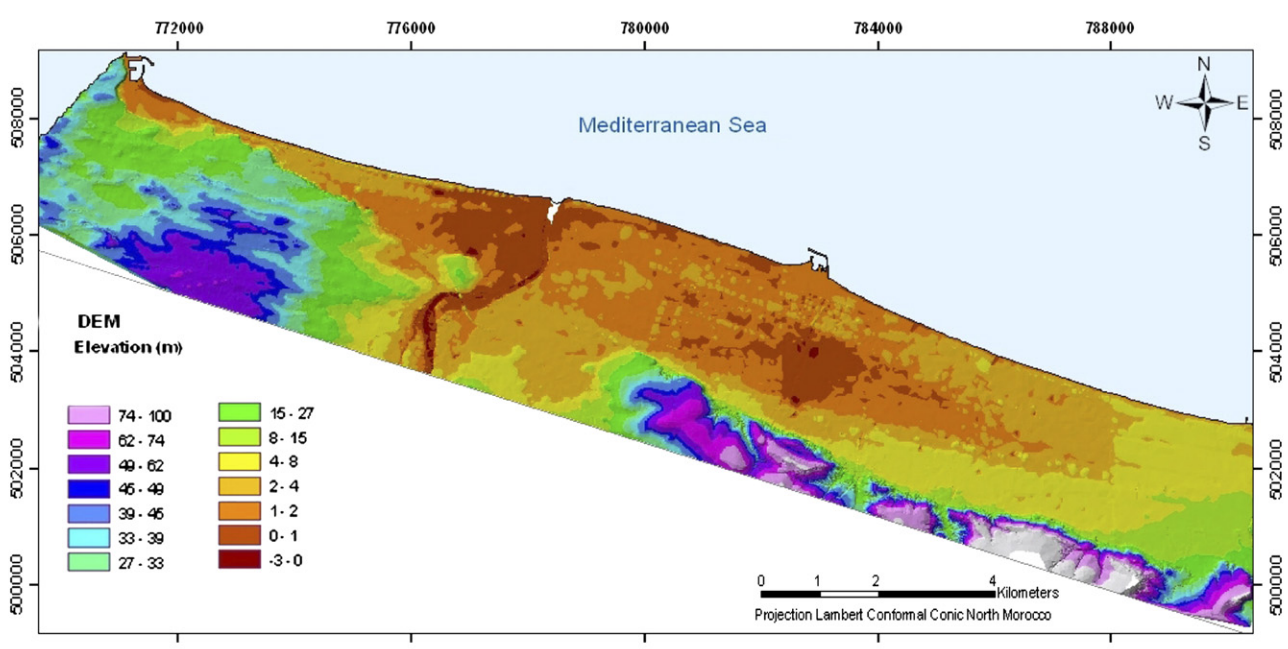

Fig. 3. Digital elevation model of the eastern Mediterranean coastline of Morocco. For interpretation of the references to color in the text, the reader is referred to the web version of this article.

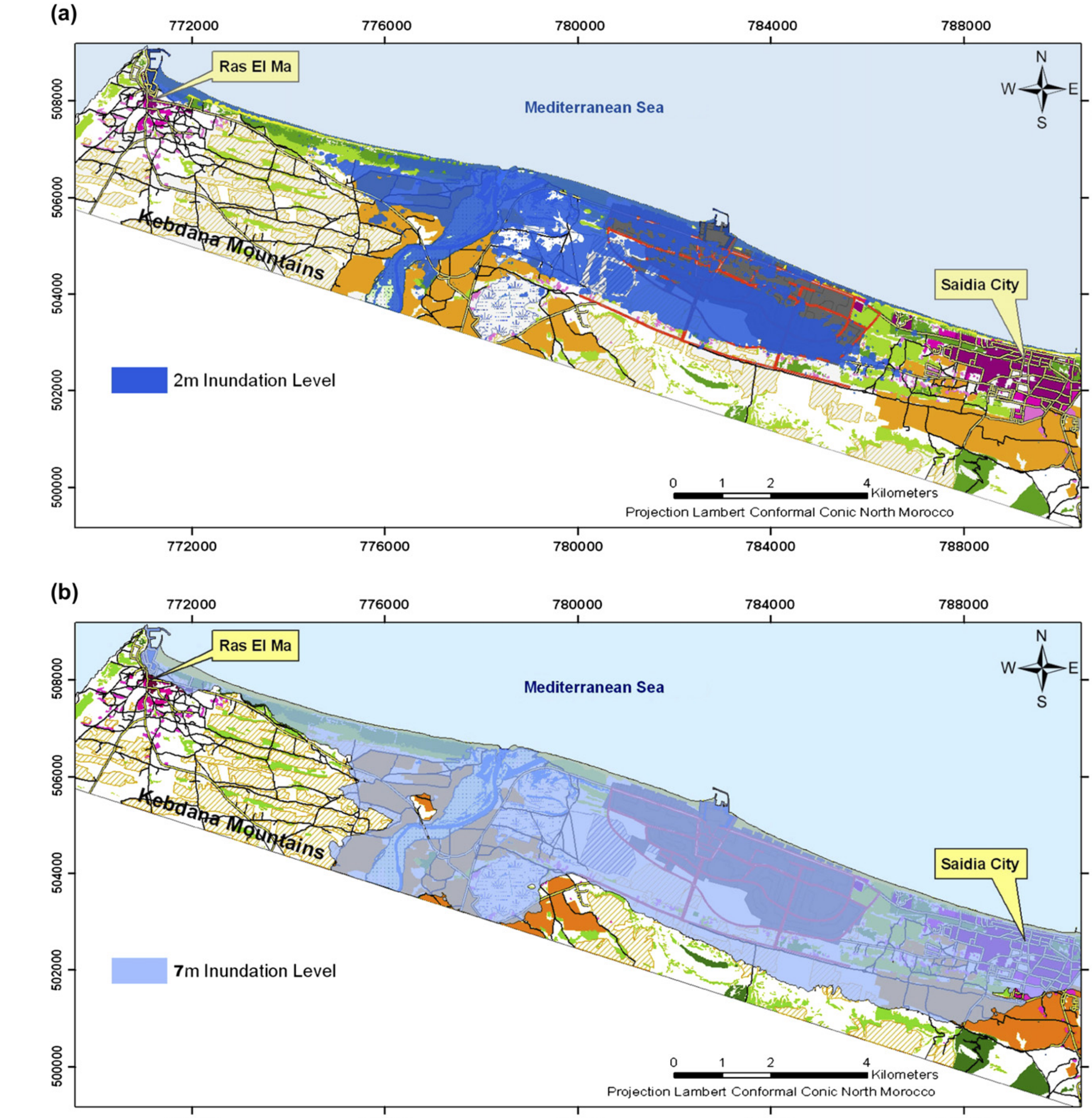

Fig. 4. Land area vulnerable to flooding (further details in text). (a) With the minimum inundation level of 2 m; (b) with the maximum inundation level of 7 m. For interpretation of the references to color in the text, the reader is referred to the web version of this article.

It was assumed that $G = 1$, on the basis that all the eroded material remained within the nearshore profile. According to Nicholls et al. (1994), high and low closure depths were estimated, based upon a time-scale of 1 year and 100 years, giving low and high estimates for shoreline retreat. Depths of closure were related to a datum of 1 m above low water. Calculations were performed on three ‘homogenous’ coastline segments that were defined mainly by the width of the active profile which varied slightly along the coast of the study area. Minimum and maximum values of land loss were presented in m^3 and as a percentage of the total sand area.

3.5. Socio-economic impacts

Having determined the land loss due to erosion and inundation, the impacts of this loss were evaluated for the major socio-economic sectors (urban and tourist areas, agricultural land) and for the natural ecosystems at risk; this was undertaken by overlaying maps for both inundation scenarios and land use. However, these images did not represent the possible future for the region, because they were based on the current socio-economic status; the impacts of scenarios for predicted inundation should be linked with equivalent scenarios for socio-economic change. The latter were not easy to predict, as they depended on the nature of future development and the way the authorities might manage the coastal environment.

Due to the lack of information on socio-economic change in Morocco, two plausible alternative futures were considered for this study, based on some assumptions drawn from the 'Africa Region scenario' (GEO-4, in press):

(1) *'Economic development first' scenario:* coastal zone of the study area will continue to be the location and concentration of economic and tourist activity. Political efforts are consolidated through policy drive to exploit natural resources, develop infrastructure and practices driven by profit goals. This scenario imposes a high level of stress upon the environment and natural resources. Science and technology aim at improving efficiency and emphasizing profitability.
(2) *'Sustainability first' scenario:* demographic trends (population growth and urbanisation rate) are favourable. There is multi-stakeholder participation, broad alliance between public and private sector, science/knowledge community, and a development of the capacity to implement policy. Pressures on the ecosystems, such as the Moulouya wetland, are reduced through careful and appropriate land use planning. More land is protected by local and national regulatory and governance mechanisms.

These qualitative storylines are of course subjective and need to be further developed and quantified so as to provide the inputs to an integrated assessment (IA), as defined by the IPCC (2001). Indeed, the IA would be the best tool to produce policy-relevant guidance to the stakeholders (Shackley and Deanwood, 2003; Holman et al., 2005).

4. Results

The DEM presented in Fig. 3 shows that low-lying land is more extensive at the east coast. The areas lower than 2 m above mean sea level (MSL), which are at risk of inundation under the minimum inundation level, are located in the interdune hollows on the eastern side of the Moulouya and on the western side of the Moulouya wetland.

4.1. Land losses due to inundation

The main results of land loss due to inundation are presented in Fig. 4a and b. The most significant changes would occur on the Moulouya delta and over the eastern part of the study area, where there is low-lying land and the natural coastal defences, such as dunes, have been destroyed. At the minimum inundation level (2 m in Fig. 4a), 24% of the total area (Table 3) would be flooded including: urban areas; natural vegetation and agricultural land; and beaches and marshes.

At the maximum inundation level (7 m in Fig. 4b), 59% of coastal land would be under direct risk of flooding including: the cities of Saïdia and Ras El Ma; the ports and the tourist resort; agricultural land; most of the Moulouya coastal wetland; beaches 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 Moulouya wetland 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. The area least vulnerable to inundation would be the western part of the study area, because the coastal strip is narrow and is backed by the Kebdana Mountains. However, parts of Ras El Ma city and port, as well as an important recreational beach and a natural forest, would be flooded.

Table 3
Potential land loss of the main sectors for 2 m and 7 m inundation levels scenarios (in km^2 and in % of the total inundated areas)

		Minimum inundation level (2 m)	Maximum inundation level (7 m)
Urban areas	km^2	5.35	10.14
	%	30.4	23.6
Agricultural lands	km^2	2.50	9.82
	%	14.2	22.8
Natural vegetation	km^2	2.60	6.53
	%	14.8	15.2
Marshes	km^2	1.20	3.00
	%	6.8	7.0
Beaches	km^2	1.30	1.82
	%	7.4	4.2
Ports	km^2	0	0.43
	%	–	1.0
Total	km^2	17.6	49.97
	%	24	59

4.2. Land losses due to coastal erosion

Measurements and calculations undertaken according to the Brunn rule (Table 4) indicate that, as early as 2050 and in the scenario of high sea-level rise, almost 50% of the sandy shore would be lost. Detailed calculations, by sectors, show that the western coast, from Ras El Ma to the Moulouya mouth, would be the most vulnerable.

By 2100 and in the scenario of high sea-level rise, more than 70% of the area would disappear. However, along the eastern part of the coast, where the Saïdia resort will be constructed, estimates indicate that 20–25% and 30–35% of the coast is expected to be lost by 2050 and 2100, respectively. This assessment has serious socio-economic consequences for the tourism development of the region, where the beach is an important part of the resource.

4.3. Socio-economic impacts

Under the '*economic development first*' scenario, continuing development will increase the flood risk and the impacts from inundation. Salt marshes and beaches will decline or be lost, because they are unable to maintain elevation relative to sea-level rise, or to migrate landwards. Combining this socio-economic scenario with the maximum inundation level

Table 4
Land losses due to coastal erosion in 2050 and 2100 (CC, climate change; SLR, sea-level rise)

	Land losses	Without CC	With SLR estimates		
			Low	Best	High
2050	10^3 m^2	388–425	160–175	456–500	888–975
	%	21.3–23.3	8.8–9.6	25–27.5	48.7–53.5
2100	10^3 m^2	442–486	277–303	679–744.5	1190.5–1307
	%	24.3–26.7	15.2–16.6	37.2–40.8	65.3–71.7

generates a future which is likely to be 'the worst-case' situation.

Under the '*sustainability first*' scenario: integrated coastal zone management (ICZM) and appropriate planning, including avoiding development in the flood plain around the Moulouya wetland and on the dunes, will minimise the flood risk. Managed realignment will lead to a large expansion in salt marshes and related intertidal habitats, which has additional benefits for flood-control (Holman et al., 2005). In combination with the minimum inundation level, this scenario corresponds to the 'best-case' situation for the region.

5. Response strategies and adaptation

In view of the severe losses due to sea-level rise, together with the extensive expansion in the development of the region, response strategies identifying the most appropriate adaptation options must be developed. Regarding the Moulouya coastal wetland, even if important autonomous adaptations could occur, mainly under the '*sustainability first*' scenario, the response to sea-level rise will also require planned adaptation (Klein and Nicholls, 1998). The most useful option to preserve this valuable ecosystem is to continue the efforts of rehabilitation and management initiated in the framework of the MedWetCoast Project, and to declare this wetland as a "protected area". Indeed, if the wetland evolves under natural conditions, without any 'concrete' structures, its potential for migration on to adjacent low-lying uplands, allows it to "grow with the sea". GIS information bases represent the first phase of a planned adaptation process.

On the short-term scale, the best option available for the adaptation of the Saïdia coast to rising sea level could be periodic beach nourishment, associated with breakwaters and dune afforestation, which would protect tourist resorts at risk from erosion and inundation. Building of seawalls is a high cost option; it would be used only for some settlements at direct risk of inundation. It is well known that such hard structures have adverse environmental impacts.

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 (Snoussi and Tabet Aoul, 2000). This plan should actively involve the local communities and the stake-holders. As such, engagement with climate change and implementation of policy response will be more effective (Shackley and Deanwood, 2003). The ICZM plan should also deal with impacts from both climatic and non-climatic change, ensuring that coastal development will not increase the vulnerability of the region.

6. Conclusion

Application of the IPCC methodology, to assess the vulnerability of the eastern Mediterranean coast of Morocco, has enabled quantification of the areas at risk from inundation and erosion caused by rising sea level. The results obtained indicate that the most vulnerable areas to inundation are the low-lying lands of the Moulouya delta and the eastern part of the coast, where natural coastal defences such as dunes have been destroyed. The western coast is the most sensitive to shoreline erosion. Urban settlements, including tourist resorts, would be the most affected economic sectors, followed by agricultural land.

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:

(1) the impact of sea-level rise on freshwater resources, including the saltwater intrusion and waterlogging problems should be considered;
(2) vulnerability assessments should include detailed socio-economic impacts, together with evaluation of the costs of these impacts and those of the adaptation measures; and
(3) response strategies should be based upon an ICZM approach for long-term sustainable development.

Acknowledgments

This work was carried out as part of the "Vulnerability and Adaptation Assessment to Climate Change of Morocco's Coastal Zones" UNEP Project. This project was conducted by the Department of Environment and supported by GEF. We want to acknowledge suggestions from the anonymous reviewers, which helped to improve this manuscript. We extend these thanks to John Icely and Michael Collins for their assistance in reviewing the English version of this paper.

References

Boumeaza, T., 2002. Le cours inférieur de la Moulouya: Morphologie quaternaire, dynamique fluviale et morphologie côtière du littoral entre Kebdana et Saïdia (Maroc oriental). Thèse Doc. ès Sciences, Univ. Liège, unpublished.

Bruun, P., 1962. Sea-level rise as a cause of shore erosion. Journal of Waterways and Harbors Division, ASCE, New York 88, 117–130.

Bruun, P., 1988. The Bruun rule of erosion by sea-level rise: a discussion on large-scale two- and three-dimensional usages. Journal of Coastal Research, Charlottesville 4, 627–648.

Carter, T.R., Parry, M.L., Harasawa, H., Nishioka, S., 1994. IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations. University College of London/Center for Global Environmental Research, London/Tsukuba, 59 pp.

Dakki, M., 2003. MedWetCoast Maroc: Diagnostic pour l'aménagement des zones humides du Nord-Est du Maroc. Rapport final réalisé pour le conte du Secrétariat d'Etat à l'Environnement & Département des Eaux et Forêts et de la Lutte contre la Désertification, unpublished.

GEO-4. Global Environment Outlook, Chapter 9. Background Paper for UNEP's Fourth Global Environment Outlook Report (GEO-3), in press.

Holman, I.P., Rounsevell, M.D.A., Shackley, S., Harrison, P.A., Nicholls, R.J., Berry, P.M., Audsley, E., 2005. A regional, multisectoral and integrated assessment of the impacts of climate and socio-economic change in the UK. Part I. Methodology. Climate Change 71, 9–41.

Hoozemans, F.M.J., Marchand, M., Pennekamp, H.A., 1993. Sea Level Rise. A Global Vulnerability Assessment. Delft Hydraulics, Delft/Rijkswaterstaat, The Hague, 184 pp.

Idom, 2004. Etude d'impact de la NSTS Saïdia, Rapport pour le Groupe FADESA Maroc, unpublished.

Imassi, S., Snoussi, M., 2003. Historical shoreline changes at the Moulouya deltaic coast in connection with land use effects. International Conference on Studying Land Use Effects in Coastal Zones with Remote Sensing and GIS, Antalia, Turkey, pp. 308–311.

IPPC, 2001. In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A. (Eds.), Climate Change 2001: The Scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 881pp.

Irzi, Z., 2002. Les environnements du littoral méditerranéen du Maroc compris entre Oued Kiss et le Cap des Trois Fourches. Dynamique sédimentaire et évolution. Thèse Doc. d'Etat, Univ. Mohamed 1er, Oujda, unpublished.

Khattabi, A., 2002. Etude socioéconomique de l'embouchure de la Moulouya. Rapport provisoire, MedWetCoast Maroc, unpublished.

Klein, R.J.T., Nicholls, R.J., 1998. Coastal zones. In: Feenstra, J.F., Burton, I., Smith, J.B., Tol, R.S.J. (Eds.), Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies. UNEP/Institute for Environmental Studies, Nairobi/Amsterdam, 35 pp.

Nicholls, R.J., Leatherman, S.P., Dennis, K.C., Volonte, C.R., 1994. Impacts of sea-level rise: qualitative and quantitative assessments. Journal of Coastal Research 14, 26–43 (special issue).

RGPH, 2004. Recensement Général de la Population et de l'Habitat, Royaume du Maroc, 2004, Rabat, unpublished.

Shackley, S., Deanwood, R., 2003. Constructing social futures for climate-change impacts and response studies: building qualitative and quantitative scenarios with participation of stakeholders. Climate Research 24, 71–90.

Snoussi, M., Tabet Aoul, E.H., 2000. Integrated coastal zone management programme, northwest African region case. Ocean & Coastal Management 43, 1033–1045.

Snoussi, M., Haida, S., Imassi, S., 2002. Effects of the construction of dams on the Moulouya and the Sebou rivers (Morocco). Regional Environmental Change 3, 5–12.

Warrick, R.A., Le Provost, C., Meier, M.F., Oerlemans, J., Woodworth, P.L., 1996. Changes in sea level. In: Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A., Maskell, K. (Eds.), Climate Change 1995. The Science of Climate Change. Cambridge University Press, Cambridge, UK, pp. 365–405.

Zarki, H., 1999. Evolution de la Sédimentation fluviatile en Basse Moulouya (Maroc) au cours de l'Holocène. Thesis, no. 1250, Univ. Mohammaed Ben Abdellah, Fes, 370, unpublished.

Zourarah, B., 1994. La zone littorale de la Moulouya (Maroc nord-oriental). Transits sédimentaires, évolution morphologique, géochimie et état de la pollution. Thesis, no. 1250, Univ. Mohammed V, Rabat, unpublished.