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Assessment of Costs of Sea-Level Rise in the Republic of Tunisia Including Costs and Benefits of Adaptation

Integration of Climate Variability and Change into National Strategies to Implement the ICZM Protocol in the Mediterranean

Technical report

October 2015

وزارة البيئة والتنمية المستدامة
Ministère de l'Environnement et du Développement Durable

APAL
وكالة حماية و تهيئة الشريط الساحلي
AGENCE DE PROTECTION ET D'AMENAGEMENT DU LITTORAL

PAP/RAC

Report:

Assessment of Costs of Sea-Level Rise in the Republic of Tunisia Including Costs and Benefits of Adaptation

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List of Abbreviations and Acronyms

AFED	Arab Forum for Environment and Development
AR5	Fifth Assessment Report
BRANCH	Biodiversity Requires Adaptations in Northwest Europe under a CHanging climate
CGIAR-CSI	Consultative Group on International Agricultural Research, Consortium for Spatial Information
CIA	Central Intelligence Agency
CIAT	International Center for Tropical Agriculture
CIESIN	Center for International Earth Science Information Network
CLIMATECOST	Full Cost of Climate Change
CMIP5	Coupled Model Intercomparison Project Phase 5
CV&C	Climatic Variability and Change
DEM	Digital Elevation Model
DG	Directorate-Generals
DINAS-COAST	Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea-Level Rise
DIVA	Dynamic Interactive Vulnerability Assessment
DTM	Digital Terrain Model
EACC	Economics of Adaptation to Climate Change
EEA	European Environment Agency
ESRI	Environmental Systems Research Institute
EU	European Union
FAO	Food and Agricultural Organisation
GADM	Global ADMinistrative areas
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GrIS	Greenland Ice Sheet
GRUMP	Global Rural-Urban Mapping Project
HadGEM2-ES	Earth System configuration of the Hadley Centre Global Environmental Model, version 2
HTM	Hamburg Tourism Model
ICZM	Integrated Coastal Zone Management
IMAGE	Integrated Model to Assess the Global Environment
IMPACT2C	Quantifying projected impacts under 2 degree C warming
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	IPCC Fifth Assessment Report
IPFRI	International Food Policy Research Institute
LOICZ	Land Ocean Interactions in the Coastal Zone
MSL	Mean Sea Level
PAP/RAC	Priority Actions Programme – Regional Activity Centre
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis
RCP	Representative Concentration Pathway
SeaRISE	Sea-level Response to Ice Sheet Evolution
SED	Socio-Economic Development
SLR	Sea Level Rise
SMB	Surface Mass Balance
SRES	Special Report on Emissions Scenarios
SSP	Shared Socio-economic Pathways
SRTM	Shuttle Radar Topography Mission
TIN	Triangulated Irregular Network
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US$	US Dollar
WB	World Bank
WTO	World Tourism Organisation

Summary in English

This study presents an assessment of sea-level rise impacts on the coastal regions of Tunisia using a downscaled version of the DIVA framework, an integrated model of coastal systems. The assessment is based on a full representative sample of the socio-economic and sea-level rise uncertainty space employing three sea-level rise scenarios (with 21st century sea-level rise of 0.30 m, 0.51 m and 1.11 m) and three socio-economic development scenarios based on the shared socio-economic pathways (SSP). The assessment considers the sea-level rise impacts of increased coastal flooding and coastal erosion. Impacts are assessed both without adaptation and with adaptation, in the form of upgrading dikes to protect against flooding and nourishing beaches and shores to protect against erosion.

The analysis shows that the impacts of sea-level rise will be substantial in the 21st century for Tunisia if no adaptation measures are taken. Coastal flooding due to current climate variability is already an issue for Tunisia. 1,124 km^2 of the Tunisian coastal zone are currently exposed to the 1-in-100 year coastal extreme water level. The 21st century sea-level rise would increase this area to 1,666 km^2 (RCP8.5). If no adaptation measures are taken, sea-level rise and socio-economic development would increase flood risks substantially during the 21st century. The expected number of people flooded annually would increase from 140,000 in 2010 to 436,000 in 2100 and the expected annual damages could reach up to USD 45.5 billion per year in 2100. Médenine is the municipality with the biggest potential 100-year floodplain, followed by Bizerte and Sfax; Tunis, Ben Arous and Sfax have the highest asset values and population in the potential 100-year floodplain.

The analysis also shows that impacts can be reduced significantly when applying appropriate adaptation measures. In the present study we assessed the adaptation via dikes as one possible and widely applied strategy. This strategy would reduce sea-level rise impacts substantially. The strategy assessed here would require an up-front investment of US$ 18.8 billion to build initial dikes for about 86% of Tunisia’s coast and subsequent annual investments and maintenance costs increasing from about US$ 169 million per year in 2010 to US$ 220–300 million at the end of the century. While these costs are substantial, they are at least one order of magnitude lower than the avoided damage costs, which means that this strategy is highly cost efficient. It must be noted that these figures refer to the maximum length of the coast that will be considered for protection. Actual measures are likely to be restricted to smaller sections of the Tunisian coast, depending on decisions related to the actual implementation of adaptation.

Coastal erosion is expected to constitute a further issue for Tunisia. Under the high sea-level rise scenario and without adaptation, sea-level rise is projected to erode up to 520,000 m² of land annually in 2100, as erodible beaches constitute approximately 1/3 of the Tunisian coastline. Adaptation through beach nourishment would cost up to US$ 43 million annually. Nabeul, Soussè, Médenine and Bizerte are expected to be the municipalities most affected by coastal erosion. Keeping the beaches used for tourism is therefore relatively expensive while sand availability may pose further challenges.

It is difficult to compare these results to previous studies because previous studies were less comprehensive and applied different assumptions. This study has assessed impacts of sea-level rise considering a potential rapid melting of the Ice sheets of Antarctica (Brown et al., 2011), which has been the main concern in sea-level science over the last couple of years (Church et al., 2013). The highest SLR scenarios used by previous studies are therefore lower compared to the high-end scenarios used in this assessment.

Future work needs to focus on the most vulnerable regions, such as Sfax, Tunis and Médenine and assess specific adaptation options for these regions. Such analytical work should also be accompanied by an exploration of how local communities can be engaged in regional responses and including a wider range of adaptation options and strategies. Finally, coastal adaptation needs to take into account the wider objectives of coastal management and development as well as the interests and conflicts amongst diverse stakeholders, for example, the fact that protecting via dikes will not be attractive for the tourism sector.

Résumé en français

Cette étude présente une évaluation des impacts de l'élévation du niveau de la mer sur les régions côtières de Tunisie en utilisant une version à l'échelle nationale du cadre d'analyse DIVA, un modèle intégré de système côtiers. L'évaluation est basée sur un échantillon représentatif complet de l'espace d'incertitude socio-économique et d'élévation du niveau de la mer, en s'appuyant sur trois scénarios d'élévation du niveau de la mer (avec des élévation pour le 21ème siècle de 0,30 m, 0,51 m et 1,1 m) et trois scénarios de développement socio-économique sur le modèle des profils socio-économiques partagés (*SSP*). L'évaluation considère les impacts de l'élévation du niveau de la mer en termes d'augmentation des inondations et de l'érosion côtière. les impacts sont évalués avec et sans adaptation, sous forme de renforcement des digues pour protéger des inondations et le rechargement des plages et des rivages pour lutter contre l'érosion.

L'analyse montre que les impacts de l'élévation du niveau de la mer sera substantiel au cours du 21ème siècle en Tunisie si aucune mesure d'adaptation est prise. Les inondations côtières dues aux variations climatiques sont d'ors et déjà un problème pour la Tunisie. Ainsi, 1.124 km^2 de côtes tunisiennes sont aujourd'hui exposée au niveau d'eau extrême de 1–100 ans. L'élévation du niveau de la mer au cours du 21ème siècle pourrait faire augmenter cette zone jusqu'à 1.666 km^2 (RCP8.5). Si aucune mesures d'adaptation ne sont prises, l'élévation du niveau de la mer et le développement économique, feront sensiblement augmenter le risque d'inondation au cours du 21ème siècle. Le nombre de personnes potentiellement inondées pourrait passer de 140.000 en 2010 à 436.000 en 2100 et les dommages annuels escomptés pourraient atteindre jusqu'à 45,5 milliards d'USD en 2100. Médenine est la municipalité avec le potentiel de plaine inondable le plus élevé sur 100 ans, suivie de Bizerte et Sfax ; Tunis, Ben Arous et Sfax ont les plus hautes valeurs patrimoniales et les populations les plus nombreuses dans la plaine potentiellement inondable de 100 ans.

L'analyse montre également que les impacts peuvent être réduit significativement si des mesures d'adaptation sont mises en œuvre. Dans la présente étude, l'adaptation avec la construction de digues a été évaluée, en tant que possible approche et comme pratique très largement mise en œuvre. Une stratégie qui réduite très significativement les impacts de l'élévation du niveau de la mer. La stratégie évaluée ici nécessite un investissement de départ de 18,8 milliards d'USD pour construire les digues initiales pour environ 86% des zones côtières tunisiennes et des investissements annuels substantiels et des frais de maintenance qui pourraient augmenter de 169 millions d'USD en 2010 jusqu'à 220–230 millions d'USD à la fin de siècle. Bien que ces coûts soient considérables, ils sont d'un ordre de grandeur moindre que les dommages évités, ce qui revient à dire qu'il s'agit d'une approche effective en terme de coût. Il est important de noter que ces chiffres font référence à la longueur maximale de côte qui doit être considérée pour la protection. Des mesures concrètes seront le plus probablement restreintes à de plus petite section du littoral tunisien, en fonction des décisions sur la mise en place des mesures d'adaptation.

L'érosion côtière restera certainement un problème pour la Tunisie. Sous le régime des scénarios élevés d'élévation du niveau de la mer et sans adaptation, l'élévation du niveau de la mer pourrait éroder jusqu'à 520 km^2 de terres annuellement, et où les plages comptent pour 1/3 des côtes tunisiennes. L'adaptation avec rechargement des plages couterait jusqu'à 43 millions d'USD annuellement. Il est attendu que Nabeul, Sousse, Médenine et Bizerte soit les municipalités les plus affectées par l'érosion côtière. Ainsi, il sera relativement coûteux de conserver les plages en état pour le secteur touristique, où la question de la disponibilité du sable sera un défis supplémentaire.

Il est difficile de comparer ces résultats avec les études précédentes car celles-ci étaient exhaustives et mettaient en application des assomptions différentes. Cette étude a évalué les impacts de l'élévation du niveau de la mer en considérant une fonte potentiellement rapide des couches glacières de l’Antarctique (Brown et al., 2011), ce qui représente une des préoccupations majeures de ces dernières années dans les sciences liées à l’élévation du niveau de la mer (Church et al., 2013). Les scénarii SLR les plus élevés utilisés lors des études précédentes sont ainsi inférieurs comparativement au scénarii les plus élevés utilisés dans cette étude.

Les travaux futures devront se focaliser sur les régions les plus sensibles, comme Sfax, Tunis et Médenine et évaluer les options d’adaptation spécifiques pour ces régions. Un tel travail analytique devrait être accompagné par une exploration (i) des modalités d’implication des communautés locales dans la définition de réponses régionales et aussi (ii) d’un plus large panel de possible options et stratégies d’adaptation. Au final, l’adaptation côtière nécessite une prise en compte plus large des objectifs de la gestion et du développement côtier, ainsi que les intérêts et conflits entre les diverses parties prenantes, par exemple, le fait que les protections avec digues ne seront pas très attractives pour le secteur touristique.

1 Introduction

The “Integration of Climatic Variability and Change into national strategies to implement the ICZM Protocol in the Mediterranean (the Climate Variability project)” has been designed to support the implementation of the ICZM Protocol in the Mediterranean. The objective of the project is to create an enabling environment for the integration of climatic variability and change (CV&C) adaptation strategies into Integrated Coastal Zone Management (ICZM) policies, plans and programmes of Mediterranean countries by (i) strengthening the understanding of the impacts of CV&C on the coastal zones of the Mediterranean region and (ii) establishing the needed information exchange mechanisms, capacity and regional pilot experiences.

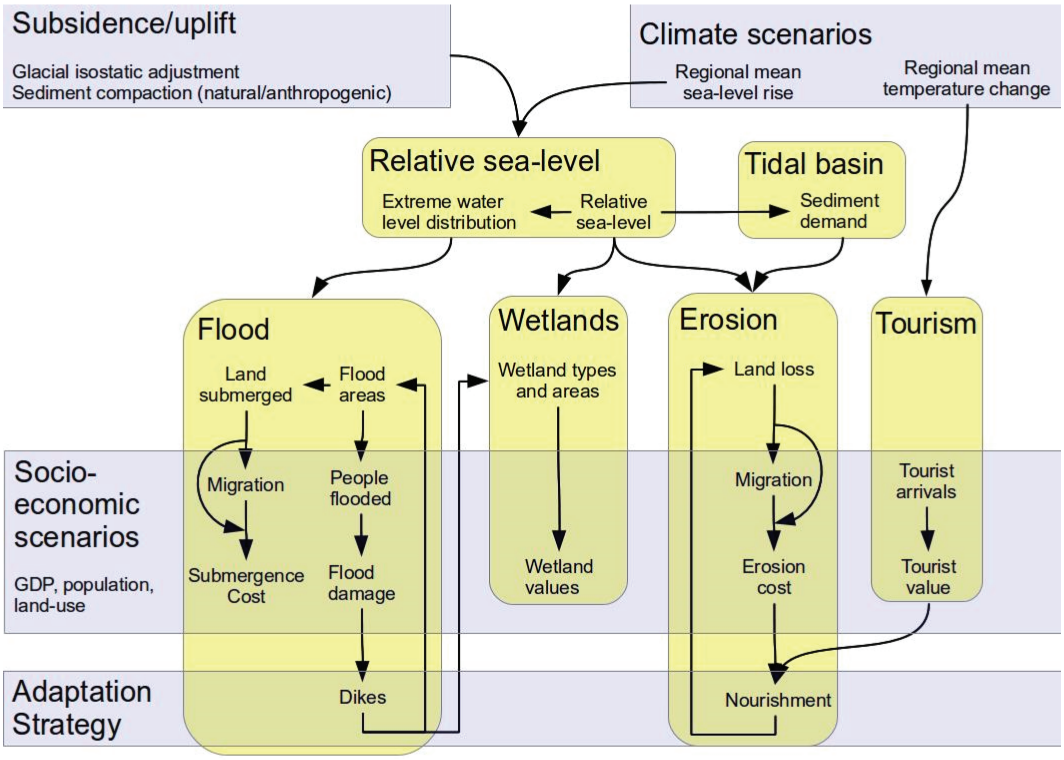
As a contribution to the second objective, a top-down, national-level assessment of sea-level rise impacts has been carried out for Croatia and Tunisia, which have been chosen as two pilot sites. This document reports the results for Tunisia.

Tunisia is inhabited by almost 10.9 million (2014 – National Institute of Statistics of Tunisia, http://rgph2014.ins.tn/en-gb/results-1) people with an annual average increase of 1.03% relative to the population in 2004 and is highly urbanized (68.8%). Accordingly to the Central Intelligence Agency (CIA) 2014, the Gross Dometic Product (GDP) *per capita* is US$ 11,400. With a GDP of US$ 121.1 billion, Tunisia is considered among the intermediate income countries (Bejaoui et al., 2012) 80% of the population is living in the coastal regions where most of the economic activities are concentrated (Missaoui et al., 2012) and about 80% of the tourism activities are located (WTO, 2003). African coastal cities are predicted to spread by 4% a year as their population grows.

The impacts of sea-level rise have been little studied at national and sub-national level in Africa. Africa has been considered in the context of global or regional assessments, such as assessments of coastal flooding and wetland loss due to global sea-level rise (e.g. Hinkel et al., 2011) and port cities and exposure to coastal flooding (Nicholls et al., 2008). However, national-scale impact assessments are not available for Tunisia to date. According to Dasgupta et al., 2011, Tunisia is ranked in the top ten (out of 84 developing countries considered world-wide) most impacted developing countries in terms of population and land potentially affected, as well as GDP loss due to a 1m sea-level rise. Heightened storm surges and an accelerated sea-level of 1 m will expose 32% of the coastal area, 32% of the population and 30% of the GDP as well as 52% of the wetland areas (Dasgupta et al., 2011) will be exposed. The second annual report of the Arab Forum for Environment and Development (AFED, 2009) considers Tunisia to be one of the four most vulnerable countries to sea level rise and estimated that over 2% of the country GDP will be at risk under a SLR of 1 meter, rising up to 3 to 5% for an accelerated sea-level of 3 m.

This report presents a novel quantitative country-wide assessment of the sea-level rise related climate impacts for Tunisia. The top-down methodology builds upon the experience of the Dynamic and Interactive Vulnerability Assessment (DIVA) model and database. DIVA is an integrated, global research framework for assessing the biophysical and socio-economic consequences of sea-level rise and associated extreme water levels under different physical and socio-economic scenarios as well as by considering various adaptation strategies. (www.diva-model.net; Hinkel and Klein, 2009). DIVA is a modular model that assesses several impacts of sea-level rise (see Figure 1 that follows). For this assessment we focus on the impacts of:

- increased coastal flood risk in terms of the expected annual damages of extreme sea-level events (storm surges), in terms of monetary damages to assets (buildings, infrastructure) and number of people affected;
- dry land loss due to increased coastal erosion due to sea-level rise and resulting damages (forced migration).



Source: Hinkel et al., A global assessment of coastal vulnerability with the DIVA model, in prep.

Figure 1: DIVA model structure. The yellow boxes show the various modules of DIVA and the grey boxes show the external data and scenario inputs.

Both of these impacts have not been assessed for Tunisia before. The aforementioned UNEP report focused on the impact of the gradual submergence of low-lying land. It is, however, important to note that even before sea-level submerges low-lying land, sea-level rise may have significant impacts by raising extreme water levels and causing coastal floods. This impact is more immediate, affects a greater area than sea-level rise submergence and is expected to be much more costly than the impact of submergence (Wong et al., 2014). This study also goes beyond previous ones in that it also quantifies the costs of adaptation strategies.

The DIVA model was co-developed with, and builds upon, a global coastal database that contains information on biophysical and socio-economic coastal characteristics (Vafeidis et al., 2008). The database relies on a segmentation of the world's coasts (excluding Antarctica) into 12,148 linear segments and associates about 100 pieces of data with each segment concerning the physical, ecological and socio-economic characteristics of the coast. This approach has been unique in the sense that it integrates data and methods for studying coastal processes from a range of different disciplines.

DIVA has been widely used for global and continental scale assessments of sea-level rise impacts, vulnerability and adaptation (e.g., Hinkel et al., 2009; Nichols et al., 2010; McLeod et al., 2010a; Hinkel et al., 2010, 2011, Vafeidis et al., 2012; Hinkel et al., 2013a; Hinkel et al., 2014). Amongst these are:

- The preparation of the 2010 State of Environment Report by the European Environment Agency (EEA);
- Costs of Adaptation to Rising Coastal Water Levels for People's Republic of China, Japan and the Republic of Korea, funded by the Asian Development Bank;
- Economics of Adaptation to Climate Change (EACC): Aggregate Track Infrastructure - Coastal Component, funded by the World Bank (WB). The project developed a global estimate of adaptation costs for informing climate negotiations and adaptation decision making;

- Economic Analysis of Coastal Adaptation to Climate Change in Senegal and Gambia, funded by the World Bank. The project assessed coastal impacts, vulnerability and adaptation using the DIVA Model for Senegal and Gambia;
- CLIMATECOST (the Full Cost of Climate Change), funded by European Commission's DG Research under the 7th Framework Programme. The project is a study of the economics of climate change to inform policy on long-term targets, the economic costs of inaction, and the costs and benefits of adaptation. The project is quantifying the costs of climate change impacts, as compared with the costs and benefits of adaptation;
- IMPACT2C (Quantifying projected impacts under 2 degree C warming), funded by European Commission's DG Research under the 7th Framework Programme;
- PESETA Project Europe: Estimation of the costs of climate change in Europe;
- BRANCH Project: Assessment of the role of climate change in European spatial planning.

For this project DIVA has been downscaled to be applicable at scales required in order to produce information useful for developing national ICZM strategies. To this end, coastal data is represented in more detail and considering the specific geographical and socio-economical context.

2 Methods and data

2.1 Coastal data and coastline segmentation

2.1.1 Overview

Based on the concept of linear representation of the coastline, DIVA employs a model of coastal space where geographic information is represented as a collection of geographic features and is referenced to coastal segments of variable length. Given the linear nature of the coast, all the data in the DIVA database are expressed as attributes of seven principal geographic features, namely coastline segments, administrative units, countries, rivers, tidal basins and world heritage sites and are all referenced to linear coastal segments which have resulted from the process of the coastline segmentation. Coastal space in DIVA has been structured to represent a meaningful expression of the spatial variability in vulnerability at the national to global scales. As variations in vulnerability within the coastal zone are controlled by primary variations in the human and physical coastal interchange, several critical parameters were employed for the segmentation of the coastline. These parameters are:

i) administrative boundaries;
ii) the geomorphic structure of the coastal environment;
iii) the expected morphological development of the coast given sea- level rise; and
iv) population density.

The segmentation of the coastline is therefore used as a means to provide a series of spatial reference units for the modelling tool of the project and to link it to the geographical database. The theoretical framework underlying the segmentation is analytically described in McFadden et al. (2007).

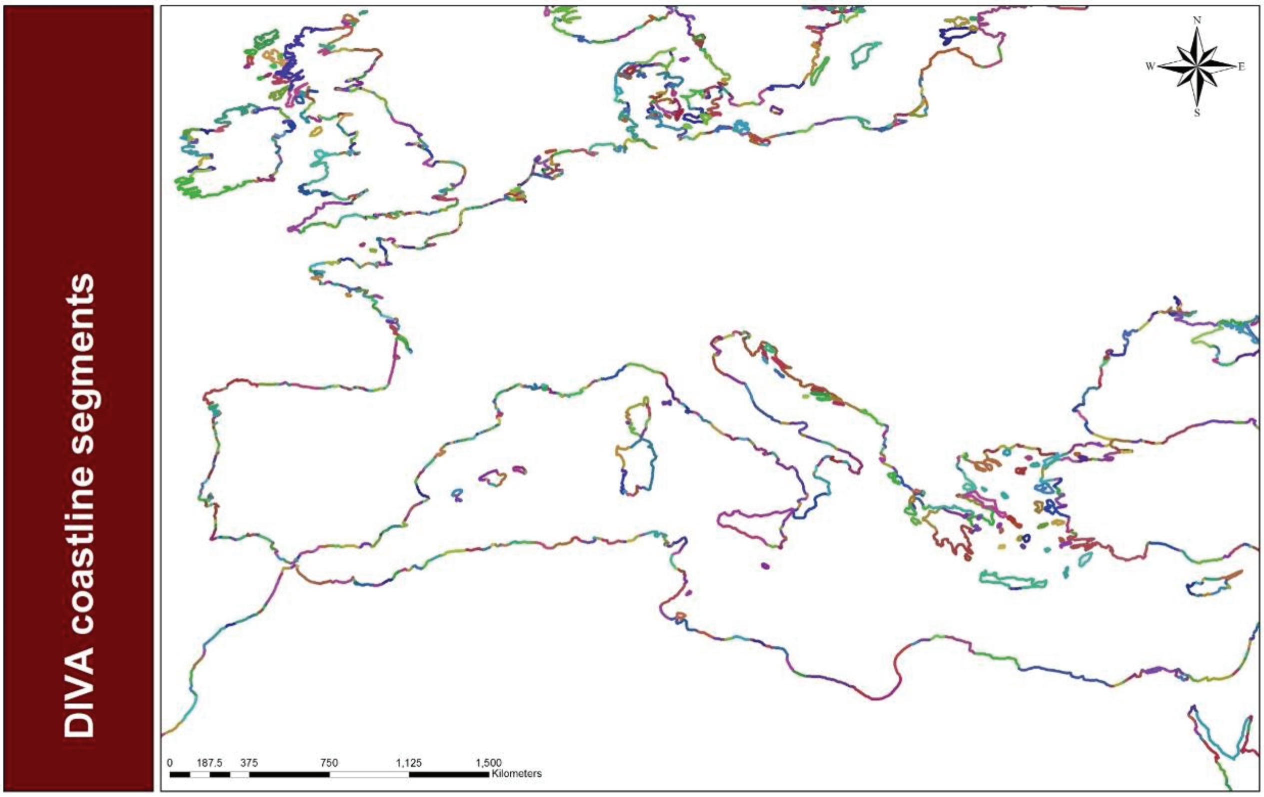


Figure 2: View of the coastline segments within the GLOBAl DIVA for the Mediterranean basin.

The segments constitute the final reference units for the DIVA model (Figure 2). All the attribute data are referenced to these segments with the use of Geographic Information Systems (GIS) and spatial processing methods that are described in Vafeidis et al. (2005). For downscaling DIVA for the national-scale assessments in Croatia and Tunisia we have developed a more detailed segmentation of the coastline and updated the DIVA database using, where possible, new and improved (in terms of resolution, accuracy, spatial coverage) spatial datasets on physical and socio-economic parameters as well as local and national datasets provided by the national organisations of the countries involved. The downscaling of DIVA involved a series of steps, which are described in the following sections.

2.1.2 Selection of digital coastline

The DIVA segmentation described above is based on a digital global coastline dataset (ESRI, 2002), with a scale of approximately 1:3,000,000. This scale involves a generalised, to a large degree, representation of coastline characteristics and was deemed inadequate for the purposes of a national scale assessment due to the loss of important coastal features (e.g. islands, enclosed bays, pocket beaches, etc.) of the countries. For this purpose, after comparing a series of available digital coastline datasets, we selected the Global Administrative Areas (GADM) level 01 coastline (http://gadm.org). The coastline was corrected using a smoothing algorithm (polynomial approximation) and a tolerance of 100 m in order to remove artefacts related to the format of source data (e.g. "pixelisation" of coastal segments). See Figure 3 for a comparison between the old and new coastlines for Tunisia.

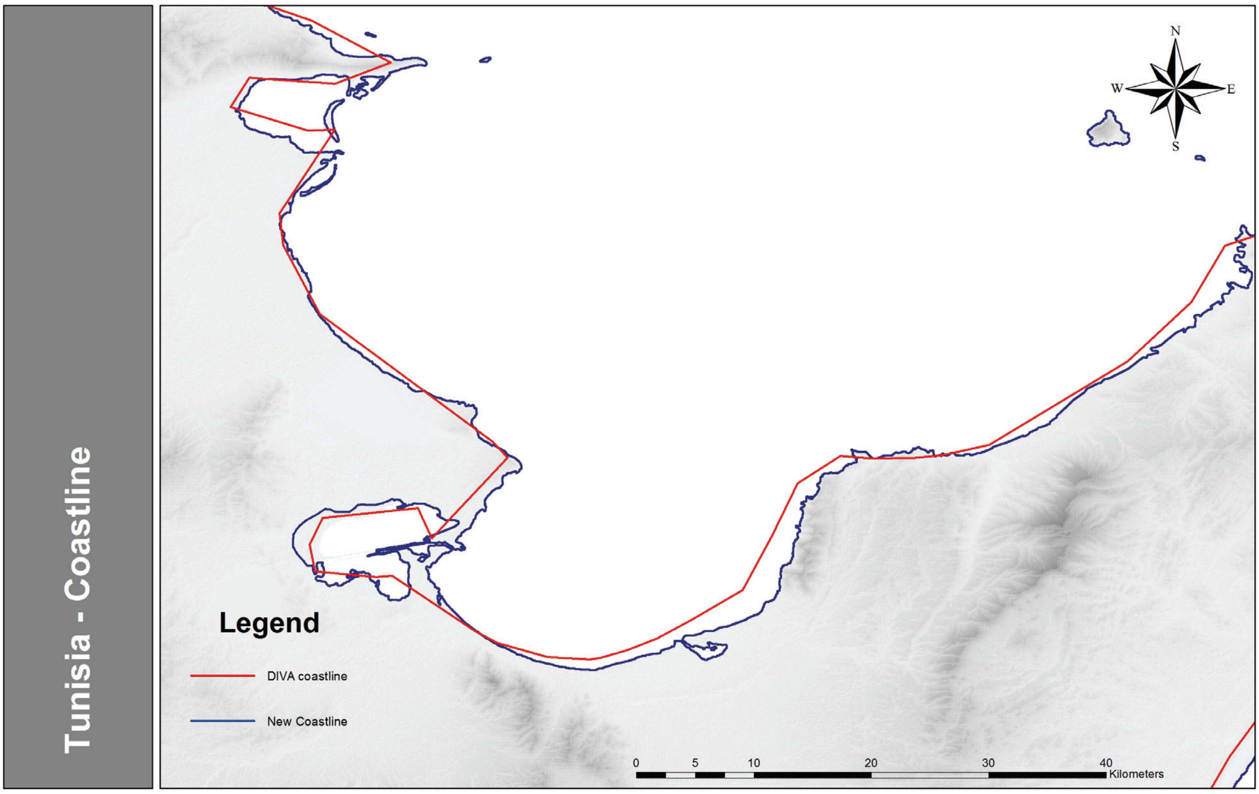


Figure 3: Comparison of global and new DIVA coastline.

2.1.3 Coastline segmentation

The coastline segmentation was based on the use of the criteria discussed in McFadden et al. (2007), namely: coastal morphology and geological characteristics; population density; administrative boundaries; and extended those criteria to also include river mouths. The availability of consistent datasets on coastal morphology and characteristics is a common limitation for global-, regional- and national-scale assessments. Although the DIVA database includes global information on coastal morphology and geological characteristics (see Vafeidis et al., 2008), for the purposes of this study we developed a new dataset on coastal morphology for the entire coastline of Tunisia. This dataset was based on visual interpretation of Google Earth imagery following the concepts described in Scheffers et al. (2012), also taking into account information included in the global DIVA database and using location-tagged photographs from the web-service Panoramio (http://www.panoramio.com). Panoramio offers geographically tagged photographs from users for the entire coastline of Tunisia, which can provide useful information on coastal type and morphology. They were used to complement/validate the satellite imagery and the cartographical information that was available, namely the geomorphic structure developed by McGill (1958). The Google-Earth imagery was further employed for the identification the boundaries of river mouths and lagoons.

For population density, all Tunisian cities with population exceeding 10,000 people (http://population.mongabay.com/population/tunisia) were considered (with the additional of some smaller ones) in the population layer. By combining this information with Google Earth imagery we developed a new spatial dataset of coastal settlements, which was then used for segmenting the coastline. Finally, a digital spatial dataset containing administrative boundaries from GADM for Tunisia has been used in order to segment the coastline.

The above information was combined to realise the segmentation of the Tunisian coastline, producing a series of linear units of variable length that represent homogeneous, in terms of response to SLR, sections of the coast. Manual corrections were applied to eliminate segments with a length smaller than 100m, as these were deemed too small for the scale of this analysis. The segmentation resulted in 563 segments (see table 1), with an average length of 3.74 km (minimum length was 101.7 metres, maximum length was 115.01 km).

Table 1: Comparison of the old (global) and new (local) coastline for Tunisia.

	Global DIVA coastline	New DIVA coastline
Number of segments	35	563
Coastline length	1,358 km	2,104 km
Segments that represent erodible beaches	10	220
Length of erodible segments	682 km	484 km

We must note that various data on coastal parameters and characteristics for the Tunisian coast were also provided by the Tunisian contact partners. These data were available in different forms (e.g. spatial, tabular, non-digital) and formats and were, in most cases, not associated with metadata. This fact rendered their use difficult in the context of this study due to time and resource constraints. Nevertheless, some of these data (e.g. information on coastal morphology, surges) were used to qualitatively evaluate the datasets that were already available. The availability of the provided datasets presents an excellent opportunity for extending the scope of this study. For example, follow-up work could focus on the update of the existing database in co-operation with the Tunisian contact point and on the use these new data to refine the results of the model simulations.

2.1.4 Exposure data – area, population and assets

Exposure of areas to inundation was assessed on the basis of the Shuttle Radar Terrain Mission (SRTM) Digital Elevation Model (DEM) (Rabus et al., 2003) according to the following series of steps:

first, we identified land areas at different elevation increments (1 m, 2 m, 3 m, ..., 16 m) that were hydrologically connected to the sea. In a second step, we produced buffer zones (with a width of approximately 200 km, which ensured that all hydrologically connected areas were included in the zones), to define inland areas corresponding to the coastline segments, and third, we calculated the extent of areas per elevation step within these zones. It must be noted that the zones were also extended seawards to account for mismatches between the elevation model and the coastline. The calculated area values were then assigned as attributes to the coastal segments.

Exposure of population was attained by summarising population per elevation increment, per coastline segment, and the resulting values were stored as attributes to the respective segments. We employed the GRUMP (CIESIN, 2004) dataset of population distribution (year 2000) and calculated the number of people per elevation increment by combining this information with the elevation data. Values were stored as attributes to the coastline segments.

For assets, a multiplication with an empirically estimated asset GDP ratio per capita of 2.8 (Hallegatte et al., 2013) was conducted. The digital datasets employed for the assessment of exposure and their characteristics are shown in Table 2.

Table 2: The digital datasets used to assess exposure of population and assets.

Dataset	Reference
SRTM 90 m Digital Elevation Data (3 arc seconds)	CGIAR-CSI (Consultative Group for International Agriculture Research – Consortium for Spatial Information). Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. (accessed 18.12.2013).
GRUMP (Population count grid, 30 arc seconds, population year 2000)	CIESIN (Center for International Earth Science Information Network), Columbia University; International Food Policy Research Institute (IPFRI); the World Bank; and *Centro Internacional de Agricultura Tropical* (CIAT); 2004. Global Rural-Urban Mapping Project (GRUMP): Urban/Rural Population grids. Palisades, NY: CIESIN, Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw.

2.1.5 Erosion parameters

We utilised the dataset on coastal morphology that was developed during the segmentation process in order to characterise the degree of erodibility of the different coastal types and to calculate the parameters for the erosion algorithm of DIVA. We implemented a slightly modified version of the method that was used in the global DIVA database (see Vafeidis et al., 2005) in order to assign new Erosion Factor values to all segments representing erodible coastal types. Based on expert judgement a value of 1 (i.e. 100% erodible) was assigned to segments that represented erodible beaches (i.e. primarily consisting of erodible material such as sand, granular gravel, or combinations of those with stones or pebbles) while a value of 0.3 was assigned to segments that consisted of rocky coasts with pocket beaches. 210 segments were identified as erodible beaches with a total length of approximately 464 km (Figure 4). Rocky and urban coasts were considered to be non-erodible and were assigned a value of zero. Erosion damages to quays and other elements of the build environment are not considered here, because they are too small scaled in order to be resolved here.

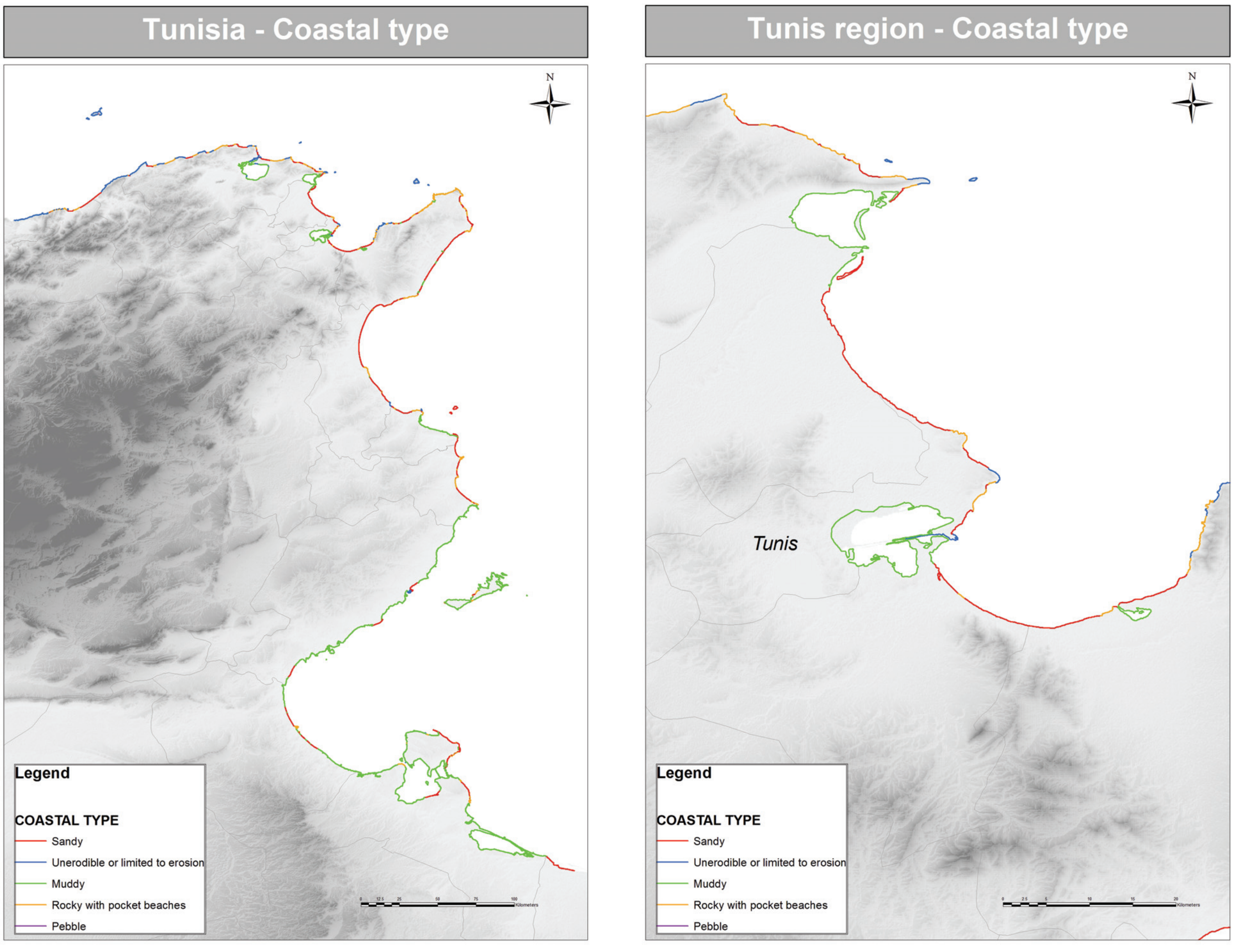


Figure 4: Coastal types in Tunisia.

2.2 Sea-level rise scenarios

The generation of regional sea-level rise scenarios follows the methodology of the Fifth Assessment Report (AR5) of the Intergovernmental Panel for Climate Change (IPCC). For each concentration scenario, we constructed regional sea-level rise scenarios. These results are based on scenarios developed in the Inter-Sectoral Impact Model Intercomparison Project Fast Track funded by the German Federal Ministry of Education and Research as published in Hinkel et al. (2014). These scenarios take into account a wider range of ice melting uncertainty than in AR5, which leads to slightly higher sea levels as compared to AR5. These scenarios are better suited for adaptation assessments than the IPCC scenarios, because according to the IPCC assessment there is a 0–33% probability that global mean sea-level rise lies outside of the IPCC range (Hinkel et al., 2015). AR5 estimates that global mean sea-level is likely to rise up to 0.98 m from 1986–2005 to 2100 under the highest greenhouse gas concentration scenario considered (RCP8.5, roughly a 4 to 5 degree world when a mid-range transient climate response is considered; Church et al., 2013). The highest estimate used in this report for the same concentration scenario and the same time period was 1.10 m (Table 3). The following four components of climate induced sea-level were considered:

- The steric contribution for the sea-level rise projections are taken for HadGEM2-ES (Collins et al., 2008) from the CMIP5 archive.
- The contribution of glaciers and ice caps to global mean sea level rise was taken from Marzeion et al., (2012). They model the past and future mass balance of all glaciers contained in the Randolph Glacier Inventory based on air temperature and precipitation anomalies obtained from the CMIP5 climate models, added to the observed climatology of New et al. (2002).

- The sea-level rise estimations coming from mass changes of the Greenland ice sheet (GrIS) and peripheral ice caps are based on surface mass balance (SMB) estimates from Fettweis et al. (2012), extended to more CMIP5 models and augmented by +20 ± 20% to account for missing dynamic processes (see Hinkel et al., 2014).
- Antarctic sea-level projections are obtained through five continental ice sheet models driven by global mean temperature change of 19 climate models. In order to obtain a probability distribution, switch-on experiments within the SeaRISE project are combined with linear-response theory. Here we use the 5%, 50% and 95% quintiles as reported in Levermann et al. (2012).

We created a low, medium and high land-ice scenario by summing up the three land-ice components along percentiles (5th, 50th, 95th) to create a "very likely" range. The overestimate of the total uncertainty – in comparison to using root mean square – is only marginal since most of the uncertainty comes from the Antarctic Ice Sheet. Global-mean sea-level change contributions from Greenland and Antarctic ice sheets are then combined with their gravitational-rotational fingerprints in order to obtain the regional contributions. We considered uniform mass loss over the ice sheets, using the same model as Bamber and Rive (2010). The fingerprints also include instantaneous, local land uplift in the vicinity of the ice sheets due to the elastic response of the solid Earth upon melting (not to be mistaken with long-term glacial-isostatic adjustment described below), thus also describing relative sea level changes. A uniform pattern is assumed for mountain glaciers and ice caps. Table 3 shows the results for the four components, Figure 5 shows the global mean sea-level rise scenarios used here.

Table 3: Global mean sea-level rise in 2100 with respect to 1985–2005.

Scenario	Model	Steric [cm]	Land-ice [cm]				Total [cm]
			Glacier	Antarctica	Greenland	Sum	
RCP 26	HadGEM2-ES	14	14 (14.15)	7 (2.23)	0 (0.0)	21 (16.39)	35 (29.52)
RCP 45	HadGEM2-ES	18	17 (16.19)	8 (2.29)	7 (5.8)	32 (23.56)	50 (41.75)
RCP 85	HadGEM2-ES	29	22 (20.26)	10 (2.41)	12 (10.14)	44 (31.81)	72 (60.110)

For the study on Tunisia we used three sea-level rise scenarios. One lower bound scenario (RCP2.6 combined with the 5% quintile of ice-melting projections), called *low SLR* below, one medium scenario (RCP 4.5 combined with the median), called *medium SLR*, and one upper bound scenario (RCP8.5 combined with the 95% quintile), called *high SLR*.

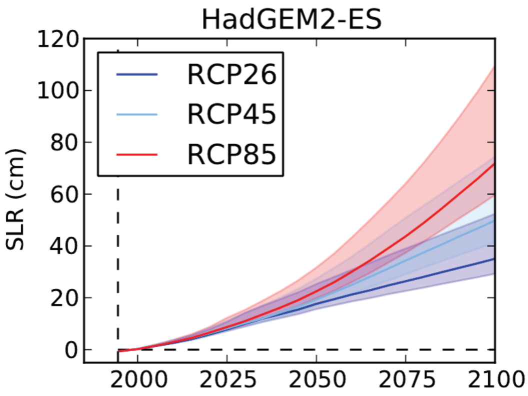


Figure 5: Global mean sea-level rise under the scenarios used here.

We also accounted for local vertical land movement due to glacial-isostatic adjustment (resulting from loading and unloading of the ice sheets during the last Ice Age) after Peltier (2000b). Natural (e.g. due to sediment compaction in river deltas) and enhanced human-induced subsidence (e.g. due to ground fluid abstraction or drainage) is not considered due to high spatial variability of this factor and also the lack of consistent observations or future scenarios. These omitted factors are, however, expected to only have a minor contribution to relative sea-level rise in Tunisia. Glacial-isostatic adjustment contributes to the submergence of land (and thus increasing relative sea level) with an average rate of 0.07 mm/year (Minimum: 0.03, Maximum: 0.08). These 0.03–0.08 cm of increasing sea-level over 100 years are a rather small contribution to the total sea-level rise shown in Figure 6.

In particular, we obtain the following values of relative sea-level rise in 2050 and 2100:

Table 4: Sea-level rise in Tunisia in 2050 and 2100 under the three sea-level rise scenarios we use.

Scenario	Sea-level rise Tunisia, 2050	Sea-level rise Tunisia, 2100
Low SLR	0.16 m	0.30 m
Medium SLR	0.20 m	0.51 m
High SLR	0.32 m	1.11 m

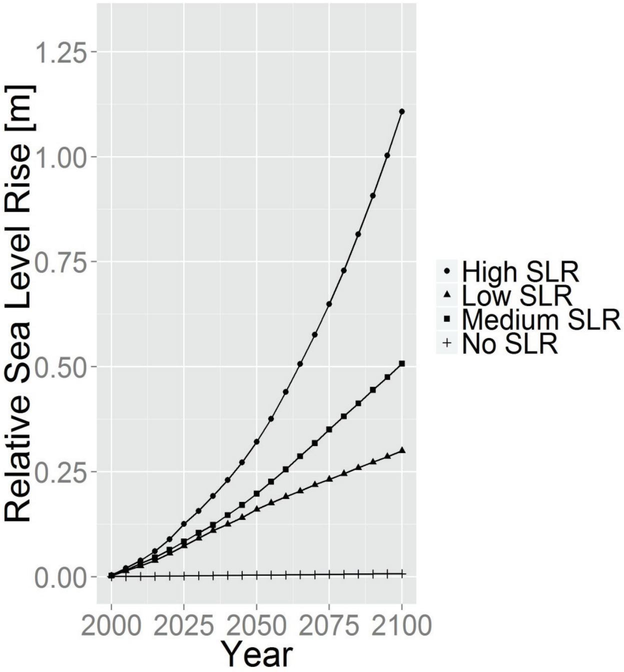


Figure 6: The average relative sea-level rise for Tunisia for the three scenarios we used.

2.3 Extreme water levels

Information on extreme water levels for different return periods are included in the DIVA database. Extreme water levels are displaced upwards with the rising sea level, as there is no clear evidence that climate change will further alter the distributions. Analysis of global tide gauge datasets shows an increase in extreme high water levels since 1970 worldwide, but also shows that mean sea-level rise is the major factor for this increase (Menendez and Woodworth, 2011).

Table 5 shows the extreme water levels used in the assessment of flood exposure and risk for Tunisia (average values over all coastline segments). H1 is the water level that is exceeded on average once every year and H100 is the water level exceeded on average once every 100 years (thus having a probability of 1% to be exceeded in a particular year). While in 2010 H1 is about 1.10 m and H100 is about 1.57 m these values go up with sea-level rise. H100, for example, will be 2.63 m under RCP8.5 in 2100.

Table 5: H1 and H100 in 2010, 2050 and 2100 under different SLR scenarios.

Scenario	H1, 2010	H1, 2050	H1, 2100	H100, 2010	H100, 2050	H100, 2100
Low SLR	1.09 m	1.22 m	1.36 m	1.55 m	1.69 m	1.83 m
Medium SLR	1.10 m	1.26 m	1.57 m	1.56 m	1.73 m	2.03 m
High SLR	1.10 m	1.39 m	2.17 m	1.57 m	1.85 m	2.63 m

2.4 Socio-economic scenarios

One of the most important drivers of coastal climate change and climate variability impacts is socio-economic development (SED). SED determines how much assets and people will be located in the coastal zone and thus be at risk of experiencing coastal impacts. Future socio-economic development cannot be predicted but must be explored through the use of socio-economic scenarios.

Here we use the state-of-the art socio-economic scenarios in the form of five population and gross domestic product (GDP) growth scenarios based on the shared socioe-conomic pathways (SSP 1–5; Arnell et al., 2011; O'Neil et al., 2014. Each SSP represents different assumptions about future global and national development. See Table 6 for global GDP and population in 2050 and 2100 and Figure 7 for national level estimates for Tunisia.

The highest GDP and lowest population numbers are attained under SSP1 (called “Sustainability”), which reflects a world progressing towards sustainability with reduced resource intensity and fossil fuel dependency, and SSP 5 (called “Conventional Development”), which reflects a world oriented toward equitable rapid fossil fuel dominated development. GDP is lowest and population highest under SSP 3 (“Fragmentation”), which reflects a world fragmented into poor regions with low resource intensity and moderately healthy regions with a high fossil fuel dependency. GDP and population under SSP 4 (“Inequality”), which is a highly unequal world both within and across countries, follow a similar but less extreme trend as compared to SSP3. SSP 2 (“Middle of the Road”) reflects a world with medium assumptions between the other four SSPs.

For this analysis we focus on the SSP2, SSP3 and SSP5, as these three scenarios sufficiently span the full uncertainty space. The respective growth rates are applied to the population and assets exposure data. The population and GDP per capita for Tunisia are shown in Figure 7.

Table 6: Global population and GDP in 2050 under different SSPs.

	Population (in millions)		GDP (billion US$/y)	
SSP	**2050**	**2100**	**2050**	**2100**
SSP1	8,400	7,200	295,000	771,000
SSP2	9,300	9,800	260,000	685,000
SSP3	10,300	14,100	169,000	355,000
SSP4	9,400	11,800	242,000	462,000
SSP5	8,500	7,790	348,000	1,207,000

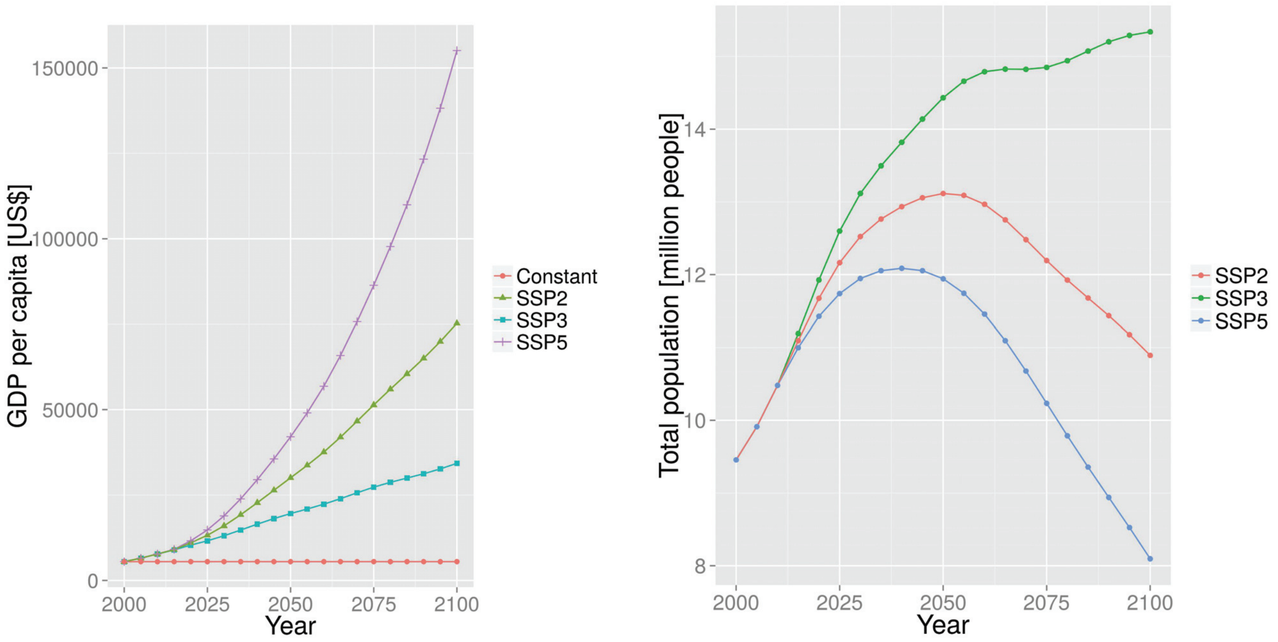


Figure 7: GDP per capita and Population in Tunisia under the three SSP scenarios used.

Table 7 summarizes population and GDP per capita in 2050 and 2100 for the SSPs used in this study. For Tunisia the GDP per capita grows in all scenarios reaching between US$ 34,290 and US$ 155,090 in 2100. Population figures grow under all scenarios until 2035. Afterwards, population starts to decline and drops to 8 million for SSP5 in 2100. For SSP2 we have a growing population until 2050, which drops afterwards and decreases to 10.9 million people in 2100. In SSP3 the population grows throughout the century and reaches 15.3 million people in 2100.

Table 7: Tunisian population and GDP per capita in 2050 and 2100 under different SSPs.

	Population in Tunisia [million]		GDP *per capita* (Tunisia) [thousand US$]	
Scenario	**2050**	**2100**	**2050**	**2100**
SSP2	13.12	10.89	30.04	75.26
SSP3	14.43	15.34	19.57	34.29
SSP5	11.94	8.09	42.06	155.09

2.5 Assessment of erosion impacts

The impacts of sea-level rise in terms of increased erosion of sandy beaches are assessed following Hinkel et al. (2013a) in terms of the following three metrics:

- **Land loss**: annual loss of land [km²/yr];
- **Migration cost**: annual costs of forced migration due to land loss [million US$/yr];
- **Nourishment cost**: annual cost of replacing eroded sand through beach or shore nourishment [million US$/yr].

Beach erosion can occur at a range of time-scales (Stive et al., 2002, 2009). Individual storms will generally lead to rapid short-term erosion, followed by rapid short-term accretion and the net change is often negligible. If sediment deficiencies persist, more chronic long-term erosion can result. This paper addresses such chronic long-term erosion due to sea-level rise. Erosion is computed following Hinkel et al. (2013a). This approach first computes horizontal recession rates based on the Bruun (1962) rule, which describes how an equilibrium profile responds to relative sea-level rise in a two-dimensional sense. It considers near-shore slope and material composition and can be used to compute the total area lost due to direct erosion.

The horizontal recession rates obtained are then translated into the loss of sand volume using the length and the active beach profile height. The beach length is computed as explained in Section 2.1.5. The active profile height is the zone that responds to sea-level rise and thus is the sum of the coastal elevation above high tide (B), the depth of closure due to wave climate (D) and the tidal range (H). B is assumed to be 2 m in all calculations, following a typical value. D is estimated through wave climate data. Repetitive beach profiles show an empirical relationship between the depth of closure and the wave climate (Hallermeier, 1981; Nicholls, 1998) and this concept is widely applied in coastline change models (e.g., Ashton et al., 2001). Wave heights are taken from the LOICZ coastal typology (Maxwell and Buddemeier, 2002) and used as indicative of an annual extreme wave height. Following Hallermeier (1981), the depth of closure is approximately twice this height. Tidal range data is also taken from the LOICZ typology. See also Hinkel et al. (2013a) and Vafeidis et al. (2008).

Two main socio-economic impacts of erosion are evaluated: dry land loss and forced migration of the people living there. Dryland loss refers to the loss of habitable land. The dominant land use class per segment taken from the IMAGE Model (IMAGE Team, 2002) is used to value these losses. Generally, this is agricultural or lower value land classes (e.g. nature areas, forests or tundra). In these cases, it is assumed that should land for more valuable uses such as housing or industry be lost due to erosion, then those activities would relocate elsewhere at the expense of the dominant agricultural or lower value land. The number of people forced to migrate is calculated as the product of the land area eroded and the average population density per segment – that is, we assume that the population is spread evenly over the area. Following Tol (1995), emigration is valued at three times per capita income.

Impacts are assessed both without and with adaptation in the form of beach and shore nourishment, i.e. the replacement of eroded sand (Dean, 2002). In beach nourishment, the sand is placed directly on the intertidal beach, while in shore nourishment the sand is placed below low tide where the sand will progressively feed onshore due to wave action, following current Dutch practice (van Koningsveld et al., 2008). Shore nourishment is cheaper than beach nourishment and effective in slowing erosion, but it is less effective at sustaining the attractiveness of a beach for tourism, because the benefits on the dry beach are not felt immediately. Based on information of Deltares, we assume the unit cost of beach nourishment to be US$ 6/m^3 and of shore nourishment US$ 3/m^3.

Nourishment is applied following a cost-benefit analysis considering the damage avoided in terms of land loss, forced migration and tourism. Because both the costs and benefits are assumed to be linear functions of the amount of nourishment, segments are either fully protected (so that no damage is done) or not at all. For areas with coastal tourism, beach nourishment is the preferred adaptation option. It is applied if the combined benefits in terms of land loss, migration and tourism are sufficient. If the costs of beach nourishment cannot be justified by its benefits, then shore nourishment is evaluated to avoid land loss and forced migration. The level of tourism and tourism revenues are calculated using the Hamburg Tourism Model (HTM) (version 1), which is an econometric model of international tourism flows at a national scale (Hamilton et al., 2005a; 2005b).

2.6 Assessment of flood damage and sea-level rise impacts

Potential coastal flood damage and sea-level rise impacts are assessed following Hinkel et al. (2014) in terms of the following metrics (all elevations are reported relative to mean sea-level (MSL):

- **Area below H100 (potential floodplain)**: The area below the 1-in-100 year extreme water level [km²];
- **People below H100**: The number of people living below the 1-in-100 year extreme water level;
- **Assets below H100**: The value of assets below the 1-in-100 year extreme water level [billion US$];
- **People flooded**: The average number of people flooded annually through extreme water level events [people/yr];
- **Flood cost**: The average annual damage caused by coastal flooding [billion US$/yr];
- **Dike height [m]:** The dike height relative to MSL;
- **Adaptation cost**: The annual cost of maintaining and upgrading coastal defences [billion US$/yr].

For each coastline segment, a cumulative people exposure function that gives the number of people living below a given elevation level x is constructed by superimposing a DEM with a spatial population dataset and interpolating piecewise linearly between the given data points. Only population of grid cells that are hydrologically connected to the coast are considered. Future exposure is attained by applying national population and GDP growth rates of the socio-economic scenarios.

For people, we only make the binary distinction between flooded and not flooded, which means that the damage function is identical to the cumulative exposure function. For assets, the damage also depends on the depth by which the asset is submerged. Following Messner (2007), we assume a relative depth-damage function (a function that gives the fraction of assets damaged for a given flood depth), with a 1-meter flood destroying 50% of the assets. This function has a declining slope, reflecting the assumption that each unit increase in water depth produces increasingly less damage. The selection of 1-m depth is a good indicative value based on the available information. The damage to assets done by a flood of height x is computed by integrating from elevation level 0 to x over the product of the depth-damage function applied to the water depth (x−y) and the derivative of the cumulative exposure function applied to the elevation level y.

In the case that there are dikes, we assume that the damage is zero for floods with a height below the dike height. Dikes are built following an econometrically derived demand function for safety, which is increasing in per capita income and population density and was taken from Hinkel et al. (2014). This function estimates a coastal society's demand for safety in terms of the flood return period against which to protect. The flood return period is the inverse of the probability of an extreme water level being exceeded in a given year. A return period of 1-in-100 years, for example, refers to the flood height having an exceeding probability of 1% per year. Following this function, dikes are built and upgraded for each coastline segment in each time step (5 yr). A threshold of 1 person per square kilometre is assumed, below which no dikes are built. This means that no dikes are built on, for example, uninhabited islands. Dike capital costs are computed based on the attained dike height, coastal segment length, and dike unit costs taken from Hoozemans et al., (1993), which are assumed to be constant over time and linear in dike height. Following Hanson et al., (2011), we also calculate the maintenance costs of dikes which are at 1% per annum of the construction costs of the dikes.

Finally, we compute the people flooded and the flood cost as the mathematical expectation of the people and assets damage functions, where the probability density function of extreme water levels is derived based on extreme water levels given for different return periods in the DINAS-COAST database (Vafeidis, 2005). Future extreme levels are obtained by uniformly applying relative sea-level rise to the distribution. Hence, no changes in storm characteristics are assumed. See also Section 2.3.

3 Results

3.1 Flooding

3.1.1 Current and future exposure

This section presents results in terms of the current and future exposure to coastal flooding. Exposure to extreme water level events (i.e. storm surges) is expected to increase in the coming decades due to both rising sea-levels, which in turn raises extreme water levels, and by socio-economic development. Figure 8 shows the impacts of the sea-level rise on the area extent of the 1-in-100-year flood (area below H100). The area below H100 is expected to rise from about 1,124 km² today (2010) to 1,286 km² in 2050 and 1,666 km² in 2100 under RCP8.5.

In the Appendix we present more detailed results for administrative units and cities. Médenine is the municipality with the biggest potentially flooded area. Today's area below H100 is 443 km² and under a high sea-level rise scenario this area could grow to 574 km² in 2100. Other municipalities with large potential flood areas are Bizerte and Sfax. However, the area below H100 in Médenine is more than two times bigger than the one in Bizerte.

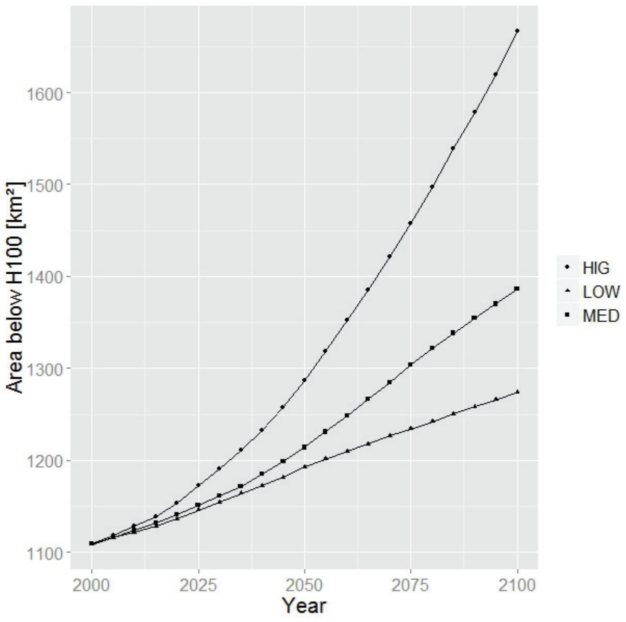


Figure 8: The potentially flooded area below H100 in Tunisia until 2100.

In terms of cities, the biggest potential flood area is in Tunis, where up to 26.6 km² could be flooded by a 1-in-100 year flood event in 2100, compared to the 16.3 km² of today. Other significant potential flood plains are in Sfax (7.3 km²) and Monastir (7.9 km²), while in Sousse (0.5 km²) and Bizerte (0.2 km²) only a small area is potentially affected in 2100.

Figure 9 shows how the exposure of assets and people in Tunisia changes under the three sea-level rise scenarios and under the three SSPs. While US$ 4,137 million asset values are below the height of the 1-in-100-year flood today, in 2050 these values range from US$ 15,805 million (low SLR, SSP3) to US$ 31,812 million (high SLR, SSP5). In 2100, our projections range from US$ 32,793 billion (low SLR, SSP3) to US$ 119,669 billion (high SLR, SSP5).

On the level of administrative units Tunis, Ben Arous and Sfax have the highest asset values in the floodplain (Table A2.1, Appendix A2). In Tunis and Ben Arous (which is south of Tunis) there are assets with values US$ 1,544 million in the coastal flood plain and this value grows to US$ 38,645 million (high SLR, SSP5) in 2100. For Sfax (municipality) we project US$ 5,332 million in 2050 (high SLR, SSP5). This value grows to US$ 16,979 million asset (high SLR, SSP5) values below H100 in 2100 (see Table A2.3, Appendix A2).

In terms of cities, Tunis has the highest asset values in the floodplain: US$ 629 million today. This value grows to 4,805 million in 2050 and 18.12 billion in 2100 (high SLR, SSP5). For the city of Sfax (today: 426 million), we project US$ 2.8 billion to US$ 7.3 billion assets below H100 in 2100 (Table A2.4, Appendix A2).

Population in the potential floodplain was calculated as 190,551 people today. In 2050 we project 238,632 (low SLR, SSP5) to 326,452 (high SLR, SSP3) people below H100, and in 2100 180,275 to 522,117 people are projected to live below H100.

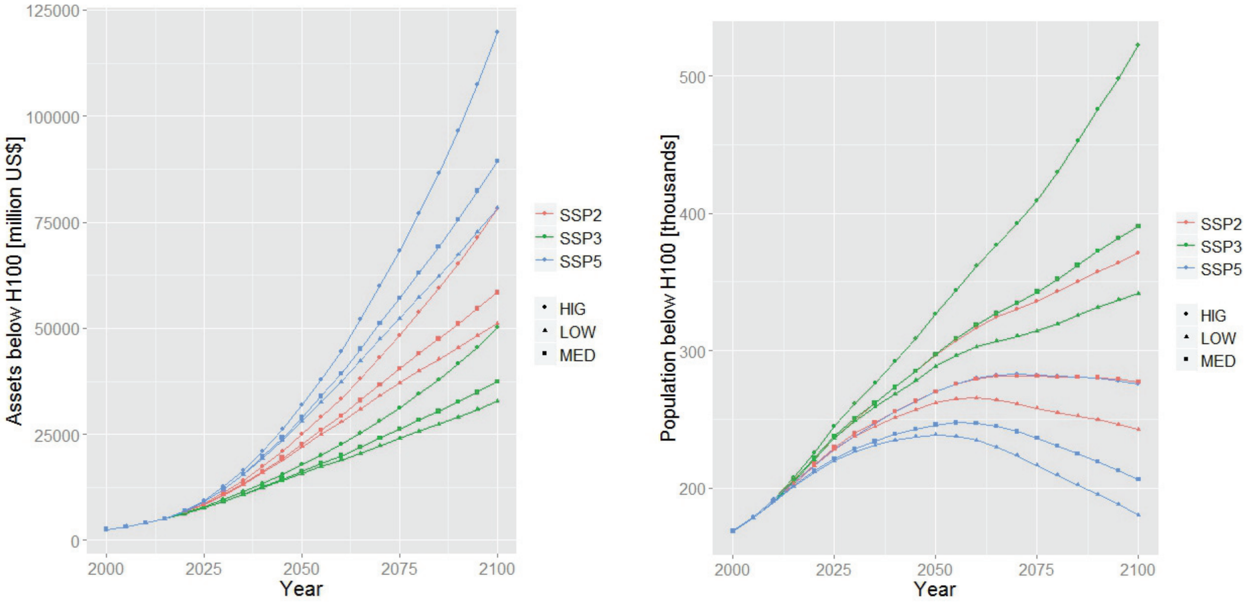


Figure 9: Assets (left) and population (right) below H100 in Tunisia until 2100.

At Municipality level Ben Arous has the highest today number of people living in the floodplain, followed by Tunis and Sfax. In Ben Arous 36,555 people live below H100 today, this value increases up to a range from 43,896 (low SLR, SSP5) to 56,452 (high SLR, SSP3) in 2050 and to a range from 31,404 (low SLR, SSP5) to 67,340 (high SLR, SSP3) in 2100.

In terms of cities Tunis has the highest population below H100, 28,973 people today, 36,448 (low SLR, SSP5) – 49,315 (high SLR, SSP3) in 2050, and 27,256 (low SLR, SSP5) – 79,093 people (high SLR, SSP3) in 2100. The second highest population below H100 is located in the city of Sfax. For Sfax (today: 19,637), we project 27,951 people in 2050 and 32,088 people (high SLR, SSP3) in 2100 living in the potential 100-year floodplain.

It should be noted that most of the uncertainty for the population exposure comes from the SSPs. Under all three sea-level rise scenarios people below H100 in 2100 could be more or less than today (expect Tunis), depending on the SSP population projection. This is not the case for assets, where under each sea-level rise scenario and each SSP the assets below H100 in 2100 are much higher (at least seven times) than today.

3.1.2 Current and future risk to people and assets

This section presents the risk of current coastal floods in terms of the number of people expected to be flooded annually and the expected annual damages to assets (building, infrastructure, etc.) as well as how this risk will increase due to sea-level rise and socio-economic development. It is important to note that risk is a statistical measure that combines information on exposure, as presented in the previous section, with information on the hazard (here sea floods) and vulnerability as described above. Risk measures should not be confused with actual damages of floods. Actual damages and risk measures can only be compared over long time-horizons. All results below assume that no protection measure are in place or will be built in the future.

Figure 10 shows the average number of people flooded annually under different scenarios. While 2010 about 139,898 people were expected to be flooded annually, this figure could increase up to 214,677 (low SLR, SSP3), 221,116 (medium SLR, SSP3), or 242,933 (high SLR, SSP3) in 2050. It should be noted that until 2050 the number of people flooded depends almost only on the sea-level rise scenario and not on the population scenario, because the population scenarios do not differ significantly before 2050. In 2100 under the low SLR scenario 134,090–254,060 people are expected to be flooded annually, under the medium SLR scenario 156,454–294,433 people are expected to be flooded annually, and under the high sea-level-rise scenario, 230,126–436,020 people are flooded annually.

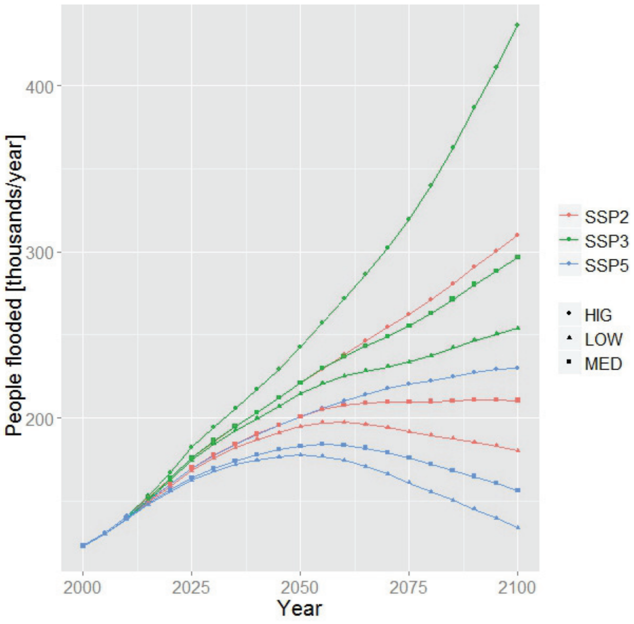


Figure 10: The average number of people flooded annually under different sea-level rise and population scenarios.

Looking at local results we find that the municipalities of Sfax, Ben Arous and Tunis have the highest number of people at risk to be flooded annually (Figure 11; see also Table A3.1 in Appendix A3). This is not very surprising as Ben Arous, Sfax and Tunis also have by far the largest number of people living in the 100-year floodplain. In Tunis in 2050, 10,139 people are expected to be flooded annually in a high sea-level rise scenario and in 2100 this number could increase up to 78,950. In Ben Arous in 2050, 25,146 people are flooded annually and in 2100 this number could increase up to 64,394 under a high sea-level rise scenario. Other municipalities with a large number of people flooded are Sfax, Mahdia and Bizerte. In terms of cities (Tables A3.2 and A3.4) Tunis and Sfax have the highest number of people flooded.

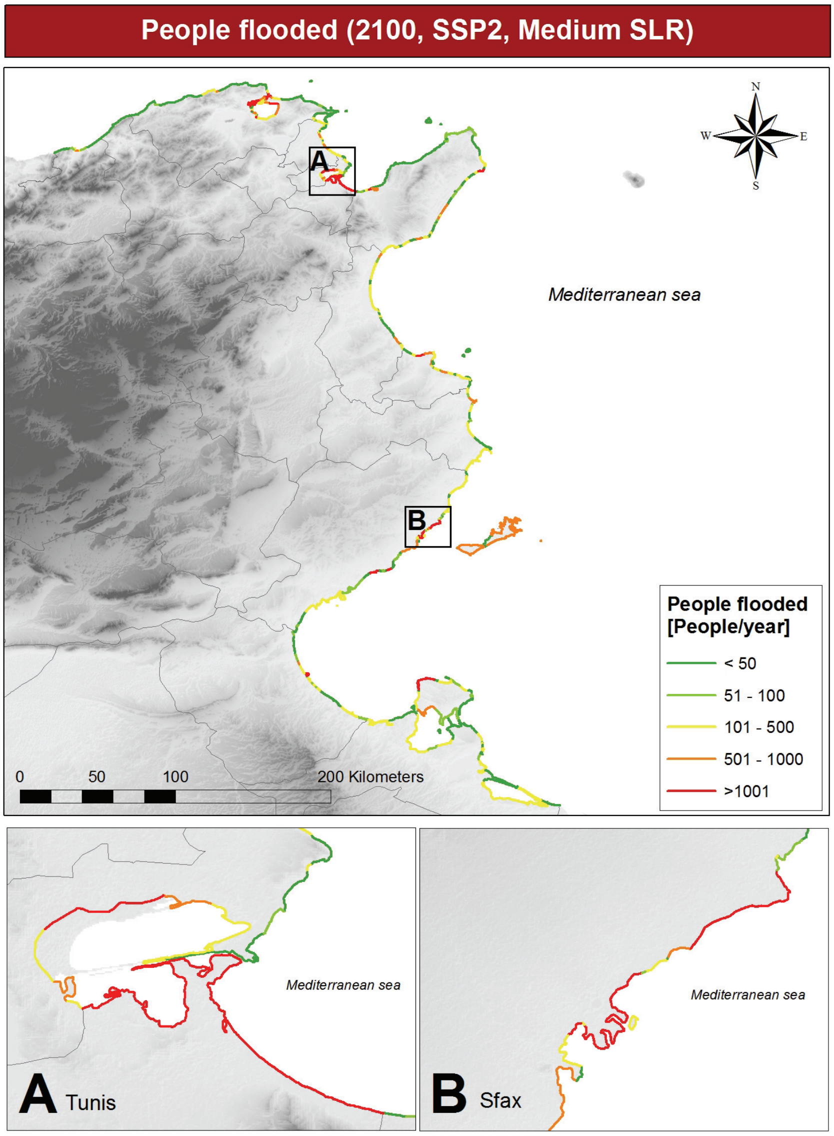


Figure 11: Annual number of people flooded in 2100 under SSP2 and the medium SLR scenario.

Figure 12 shows the expected annual sea-flood cost for all of Tunisia. In 2010 the expected annual flood cost are US$ 1033 million. Under the high sea-level rise scenario the annual damages by sea-floods grow up to a range from US$ 5.1 billion to US$ 9.0 billion in 2050, and in 2100 we project US$ 19.1 billion to US$ 45.5 billion average annual damages by sea floods. Under the low sea-level rise scenario the expected damages are much lower, ranging from US$ 4.2 billion to US$ 7.5 billion in 2050 and from US$ 9.3 billion to US$ 22.1 billion in 2100.

On local level the municipalities of Sfax, Ben Arous and Tunis suffer the highest expected damages from sea floods. As shown in Tables A4.1 and A4.3 Tunis has expected sea-flood costs of US$ 166 million in 2010, which grow to the range US$ 685 million to US$ 1,218 million under the low SLR scenario and to the range between US$ 827 million to US$ 1,470 million under the high SLR scenario in 2050. By the end of the century, Tunis has expected sea-flood costs are in the range US$ 1,502 million to US$ 3,586 million for the low SLR scenario and in the range US$ 3.3 billion to US$ 7.9 billion in the high SLR scenario. Sfax has the highest expected damages from sea floods, ranging from US$ 2.0 billion to 4.9 billion and from US$ 3.4 billion to 8.0 billion in 2100.

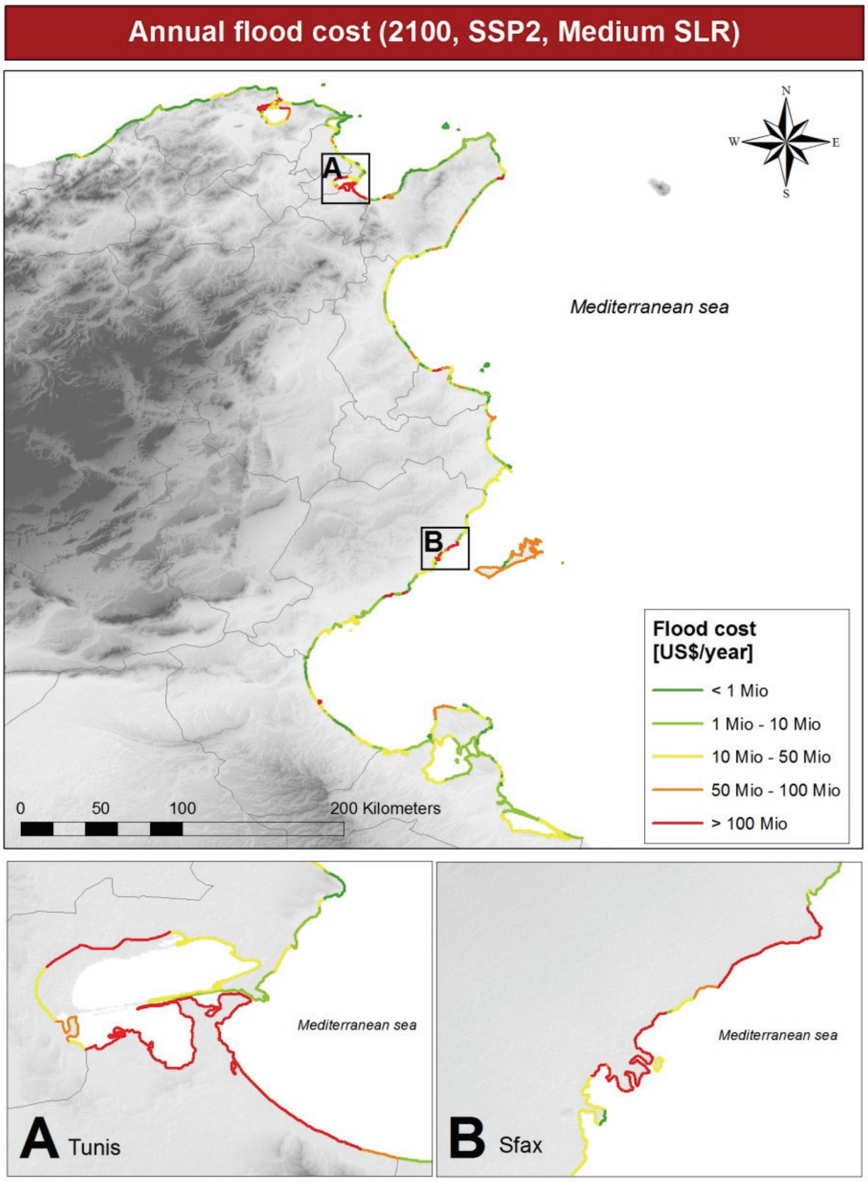


Figure 12: Annual flood cost in 2100 under SSP2 and the medium SLR scenario.

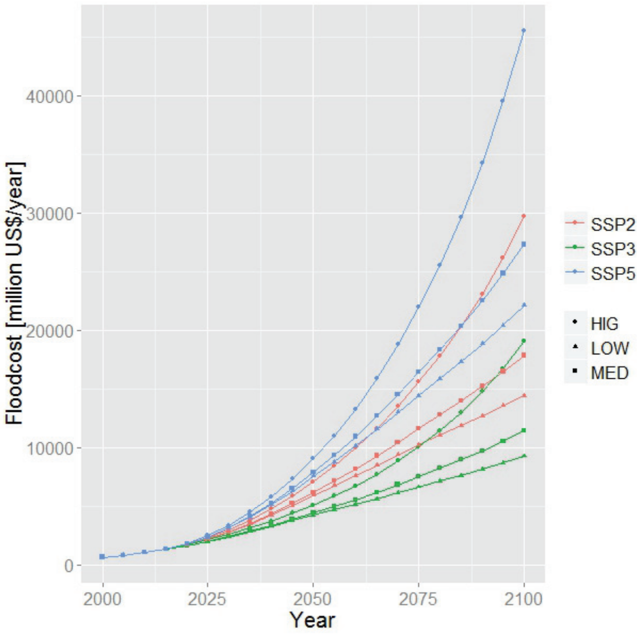


Figure 13: Expected seaflood cost in Tunisia under different sea-level rise scenarios and socio-economic scenarios until 2100.

At city level Sfax and Tunis are most affected. While today's average annual damages by sea-floods are computed as US$ 153 million and 145 million respectively. In 2100 the projected range of sea flood cost in Sfax is US$ 1.2 billion to US$ 4.3 billion, depending on the sea-level rise scenario and the SSP. Expected damage costs in Tunis (2050: US$ 602 million (low SLR, SSP3) are lower than in Sfax until 2050. In 2100, Tunis has the highest expected damages from sea floods, ranging from US$ 1.3 billion to US$ 6.5 million in 2100.

3.1.3 Adaptation costs

All impacts reported in Section 3.1 and 3.2 are assessed with the assumption of no adaptation measures being in place. In this section we assess the potential costs of reducing coastal flood damage and impacts through constructing dikes. Generally, a wide range of coastal adaptation measures are available including: i) protection against flooding through, e.g. building dikes or restoring coastal ecosystems, ii) accommodation measures such as flood-proofing houses and critical infrastructure, and iii) retreat from the coastline (Klein et al., 2001; Wong et al., 2014). This analysis focuses on dikes because this is the most common and mature technology applied in heavily human used coastal zones. By considering dikes we do not want to suggest that this should be the sole measure applied. Which long term strategy to take for protecting Tunisia against sea-level rise is a decision that needs to be taken by all involved stakeholders. The cost estimates generated here may support this process.

In our analysis we distinguish between protecting coats against current climate variability and future climate change. In our case, adapting to current climate variability means constructing dikes to protect against the current extreme water level regime. We thereby estimate the design height of dikes through an econometric demand-for-safety function that is in increasing in population density and GDP and is taken from Hinkel et al. (2014) as explained above.

To adapt to current climate variability in 2010, dikes with an overall length of 1,856 km and an average dike height of 1.73 m would be needed to protect 86% of Tunisia's coastline. It must be noted that these figures refer to the threshold of 1 person per km^2 that is discussed in the methods, and thus this value represents the maximum length of the coast that would be considered for protection (i.e. all inhabited places). Actual measures are likely to be restricted to smaller sections of the Tunisian coast, depending on decisions related to the actual implementation of adaptation. In this assessment dikes are built following the demand function for safety as described in Section 2.6, which means that more densely populated areas are protected with higher dikes. No dikes are built in uninhabited coast-line segments. Please note that while we only assess dikes as an adaptation option, there are many more adaptation options available, including retreat options such as establishing set back zones. The average design return period is about 1-in-400 years in 2010. Constructing these dikes would require an investment of US$ 15.8 billion (Table 8). These costs represent what is called adaptation deficit in the literature. Usually, these costs would be distributed over time. Assuming a planning and implementation horizon for coastal defences of 50 years (Nicholls et al., 2010a) would mean that US$ 315 million per year would need to be spent over 50 years.

Table 8: Dike construction and maintenance cost.

	Construct. cost [million US$]	Maint. cost [million US$]	Total [million US$]	Avoided annual flood damages [million US$]
Initial cost	15,789	N/a	6,830	N/a
Annual cost, 2100	63–111	166–169	229–449	1,018-1,035
Annual cost, 2100	39–221	219–302	258–523	19,004–49,428

Adapting to future climate change means upgrading existing and constructing new dikes in order to account for the increasing risks. The additional construction and the maintenance cost for this is shown in Figure 14. Annual costs increase with sea-level rise. In 2050 and under the high SLR scenario, about US$ 77–149 million per year would need to be invested in upgrading dikes and US$ 193–222 million per year in maintaining the total dike stock (i.e. about US$ 169 million for maintaining the initial dike stock build in 2010 and US$ 111 million for maintaining the additional dikes build since 2010). In 2100, US$ 221 million per year are needed for dike upgrades and US$ 302 million per year for maintenance with an average dike height of about 2.9 m under the high sea-level rise scenario (Figure 14). Under the low SLR scenario the average dike height in 2100 is 2.1 m and US$ 39 million per year to upgrade dikes and US$ 219 per year for maintaining them.

While these adaptation costs are substantial, overall adaptation is cost-efficient as it reduces the impacts significantly (Figure 15; Table 8). In 2100, annual sea-flood cost are about US$ 49.5 billion under the high SLR scenario and US$ 9.2 billion under the low SLR scenario (SSP5).

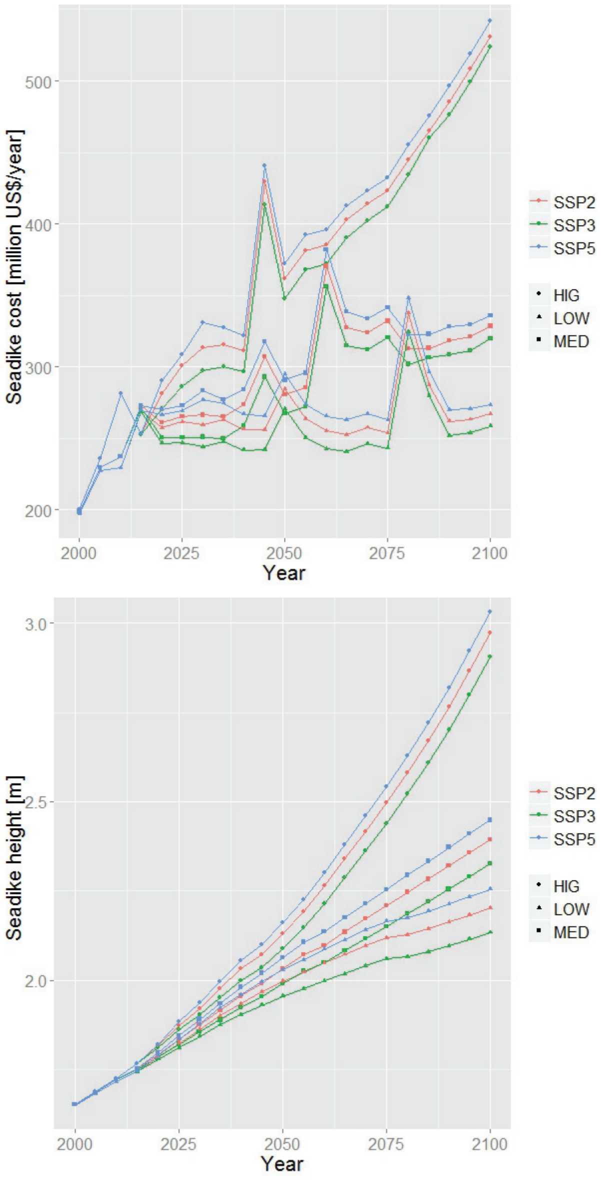


Figure 14: Annual dike construction and maintenance cost (top) and total average dike height (bottom).

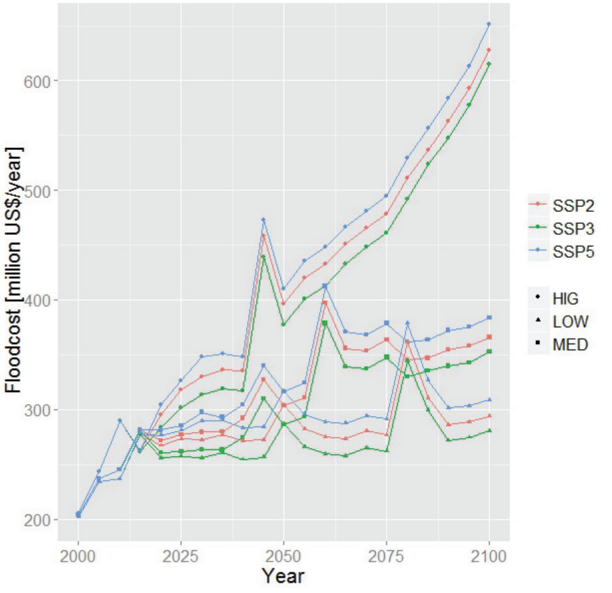


Figure 15: Expected annual coastal flood cost with adaptation.

3.2 Erosion

3.2.1 Impacts

Around one third of the Tunisian coastline consists of erodible beaches. In our classification we identified 345 segments that contain a fraction of erodible beach and the total length of erodible beaches in Tunisia is 734.2 km. Expected annual land loss due to sea-level rise is shown in Figure 16. Under the high sea-level rise scenario and without adaptation, sea-level rise is projected to erode 522,755 m² of land in 2100. Under the medium sea-level rise scenario 155,606 m² are lost and under the low sea-level rise scenario 70,814 m² are lost from in 2100.

The municipalities most affected by erosion are Nabeul (116,258 m² land loss in 2100, high SLR), Sousse (80,559 m² land loss in 2100), Médenine (76,167 m² in 2100) and Bizerte (72,048 m² land loss in 2100). The expected annual land loss due to a medium SLR is shown for every segment in 2100.

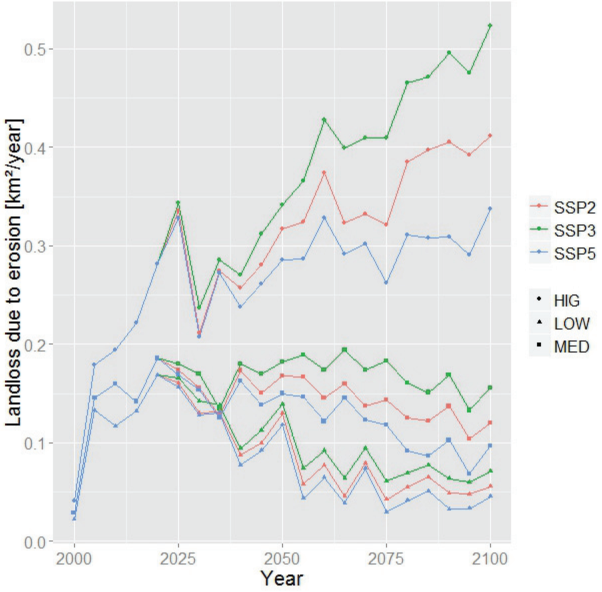


Figure 16: Annual land loss due to erosion until 2100 in Tunisia under three different sea-level rise scenarios.

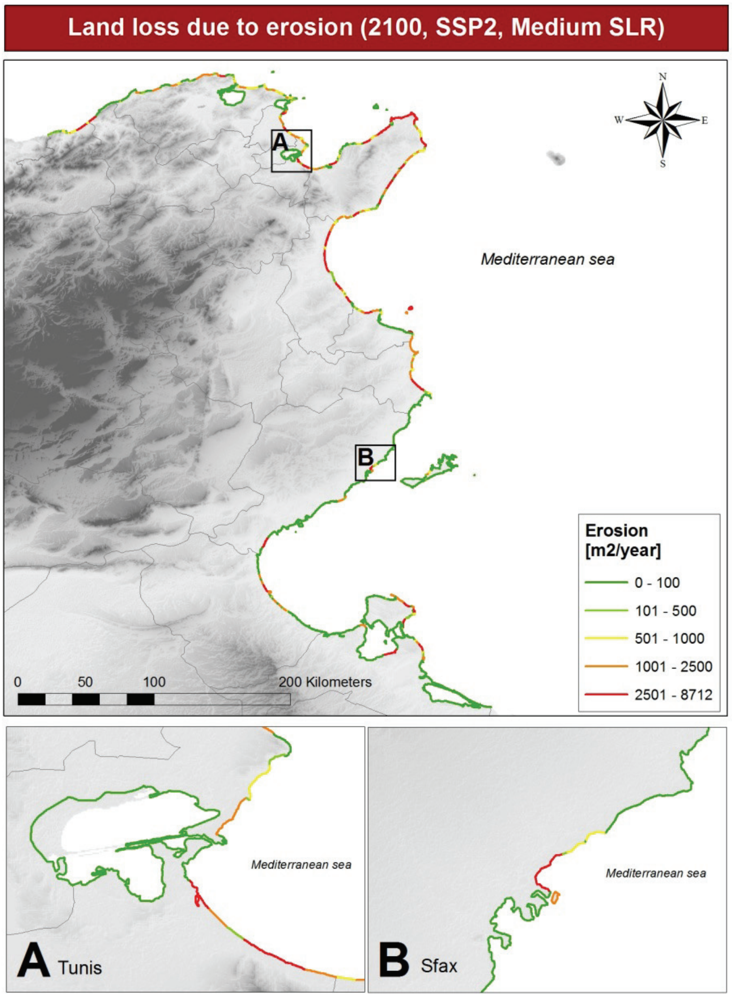


Figure 17: Annual land loss due to erosion 2100 under SSP2 and the medium SLR scenario.

3.2.2 Adaptation

Applying beach nourishment following the cost-benefit approach described in Section 2.4 will require up to 2.5 km^3 of sand to be applied annually in 2050 and up to 7,2 km^2 of sand in 2100 (Figure 18), leading to an annual cost of up to US$ 14.2 million in 2050 and US$ 43.82 million in 2100 (Figure 19). Nabeul is the municipality with the highest expected annual beach nourishment cost. The expected costs are US$ 1.5 million under a low sea-level rise scenario and US$ 3.8 million under a high sea-level rise scenario in 2050. This could grow to US$ 9.97 million under a high SLR and SSP5 in 2100. Other municipalities with high potential annual beach nourishment costs are Médenine, Monastir and Bizerte (see Table A5.2 and A5.6 in Appendix A5).

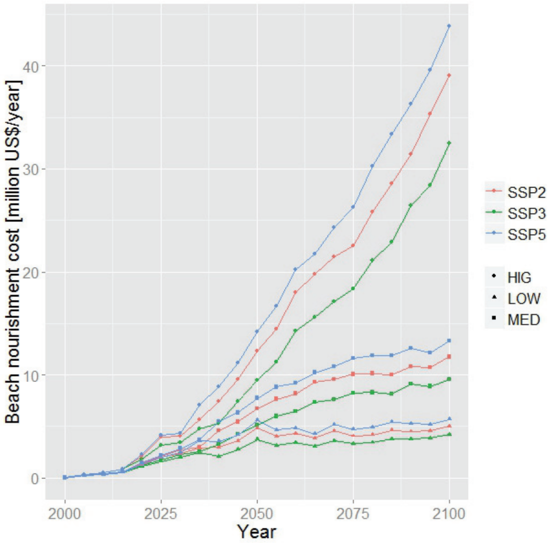


Figure 18: Annual beach-nourishment cost in Tunisia under three sea-level rise scenarios until 2100.

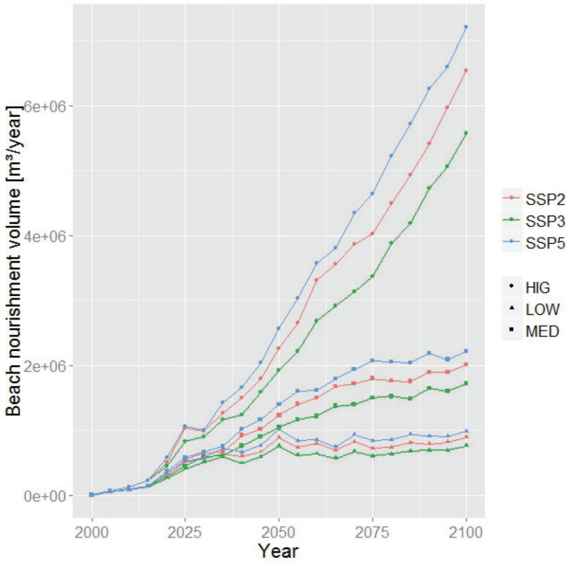


Figure 19: Annual beach-nourishment volume in Tunisia under three sea-level rise scenarios until 2100.

4 Discussion and conclusions

This report presents an assessment of sea-level rise impacts on the coastal regions of Tunisia using a downscaled version of the DIVA framework, an integrated model of coastal systems. The assessment is based on a full representative sample of the socio-economic and sea-level rise uncertainty space employing three sea-level rise scenarios (with a 21st century sea-level rise of 0.30 m, 0.51 m and 1.11 m) and three socio-economic development scenarios based on the shared socio-economic pathways (SSP). The assessment considered the sea-level rise impacts of increased coastal flooding and coastal erosion. Impacts were assessed both without adaptation and with adaptation in form of upgrading dikes to protect against flooding and nourishing beaches and shores to protect against erosion.

The analysis shows that the impacts of sea-level rise will be substantial in the 21st century for Tunisia if no adaptation measures are implemented. Coastal flooding due to current climate variability is already an issue for Tunisia as 1,124 km² of the Tunisian coastal zone are currently exposed to the 1-in-100 year coastal extreme water level. 21st century sea-level rise would increase this area to 1,666 km². Médenine is the municipality with the biggest potential 100-year floodplain, followed by Bizerte and Sfax while Tunis, Ben Arous and Sfax have the highest asset values and population in the potential 100-year floodplain in 2100. If no adaptation measures are implemented, sea-level rise and socio-economic development would increase flood risk substantially during the course of the 21st century. The expected number of people flooded annually in 2100 could increase up to 436,000 people (worst case), with an annual cost of USD 45.48 billion to USD 22.1 billion, with damages mainly concentrated in Sfax, Tunis and Ben Arous.

The analysis also shows that impacts can be reduced significantly when applying appropriate adaptation measures. Here we assess the adaptation via dikes as one possible and widely applied strategy. This strategy would reduce sea-level rise impacts by US$ 19–49.4 billion. The strategy assessed here would require an up-front investment of US$ 18.8 billion to build initial dikes for about 86% of Tunisia's coast and subsequent annual investments and maintenance costs increasing from initially US$ 169 million per year in 2010 to US$ 219–302 million at the end of the century. While these costs are substantial, they are at least one order of magnitude lower than the avoided damage costs, which means that this strategy is highly cost efficient. Nevertheless, it is unlikely that dikes can be as widely implemented as our analysis suggests due to the fact that, among others, protection by dikes is not very attractive for coastal tourism, which is a significant source of income for the country.

Besides coastal flooding, coastal erosion also appears to be a major issue in Tunisia. Without adaptation, Tunisia is expected to experience annual land loss of up to 522,755 m² in 2100 as approximately 1/3 of the Tunisian coastline consists of erodible beaches. Municipalities that are expected to be most affected by erosion are Nabeul, Sousse, Médinine and Bizerte. Adaptation through beach nourishment in 2100 would cost about US$ 43.82 million annually and would require up to 7.2 km² of sand. Keeping the beaches used for tourism will therefore be relatively expensive. It is also important to note that sand availability is currently an issue in several Mediterranean countries and this situation may accentuate in the course of the century.

It is difficult to compare these results to previous studies because previous studies were less comprehensive and applied different assumptions. For example, the study of Hinkel et al. (2010) used much more conservative estimates of sea-level rise without considering a potential rapid melting of the Ice sheets of Antarctica, which has been a main concern in sea-level science over the last couple of years (Church et al., 2013). Future work should focus on the most vulnerable regions such as Sfax and Tunis and explore specific adaptation options for these regions. Such analytical work should also be accompanied by an exploration of how local communities can be engaged in regional responses and including a wide range of adaptation options and strategies. Finally, coastal adaptation needs to take into account the wider objectives of coastal management and development as well as the interests and conflicts amongst diverse stakeholders. For example, protecting via dikes will not be attractive for the tourism sector.

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Appendix A:
Detailed Results for Municipalities and Cities

A1 Potential flood area

Table A1.1: Potentially flooded area (below H100) per administrative unit in 2050 and 2100 under different SLR scenarios compared with today's situation.

Municipality	Potential flood area [km²]						
	Today	2050			2100		
		Low SLR	*Medium SLR*	*High SLR*	*Low SLR*	*Medium SLR*	*High SLR*
Ariana	85.29	88.99	90.04	93.49	92.88	98.64	114.59
Beja	0.56	0.63	0.65	0.71	0.70	0.81	1.13
Ben Arous	10.80	11.51	11.71	12.40	12.27	13.32	16.27
Bizerte	140.03	154.60	158.86	172.96	170.43	185.17	208.94
Gabés	44.92	47.33	48.02	50.33	49.94	53.69	63.78
Jendouba	1.19	1.33	1.37	1.51	1.48	1.72	2.59
Mahdia	56.45	66.45	69.34	78.92	77.31	93.33	124.49
Médenine	443.82	459.47	464.00	478.99	476.50	501.57	574.13
Monastir	5.58	9.15	11.86	20.85	19.32	34.33	77.70
Nabeul	26.05	28.98	29.83	32.75	32.24	36.61	47.84
Sfax	213.93	222.84	225.42	233.97	232.53	246.83	281.42
Sousse	38.76	42.49	43.70	48.97	48.06	56.89	82.45
Tunis	56.88	58.62	59.13	60.82	60.52	63.25	71.02
Total	**1,124.26**	**1,192.38**	**1,213.92**	**1,286.66**	**1,274.18**	**1,386.17**	**1,666.34**

Table A1.2: Potentially flooded area (below H100) per city in 2050 and 2100 under different SLR scenarios compared with today's situation.

City	Potential flood area [km²]						
	Today	2050			2100		
		Low SLR	*Medium SLR*	*High SLR*	*Low SLR*	*Medium SLR*	*High SLR*
Bizerte	0.06	0.06	0.07	0.07	0.07	0.10	0.24
Mahdia	1.26	1.33	1.35	1.42	1.41	1.53	1.80
Monastir	0.42	0.65	0.83	1.40	1.30	2.26	5.04
Sfax	4.90	5.22	5.31	5.61	5.56	6.07	7.32
Sousse	0.17	0.19	0.20	0.23	0.23	0.29	0.46
Tunis	16.32	17.57	17.94	19.15	18.93	20.89	26.56

A2 Assets and Population in the floodplain

Table A2.1: Assets in the floodplain in 2050 under different SLR scenarios compared and SSPs compared with today's situation.

Municipality	Assets Below H100 [million US$] in 2050									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Ariana	247.05	1,736.44	1,362.09	976.55	1,796.69	1,409.35	1,010.44	1,994.63	1,564.63	1,121.76
Beja	0.10	0.68	0.53	0.38	0.70	0.55	0.39	0.77	0.60	0.43
Ben Arous	793.65	5,169.63	4,055.16	2,907.35	5,246.51	4,115.47	2,950.58	5,501.32	4,315.34	3,093.88
Bizerte	397.06	2,723.78	2,136.59	1,531.82	2,802.51	2,198.34	1,576.10	3,063.45	2,403.03	1,722.85
Gabés	85.18	602.86	472.90	339.05	625.02	490.28	351.50	698.46	547.89	392.81
Jendouba	22.88	158.32	124.19	89.04	163.27	128.08	91.82	179.69	140.95	101.05
Mahdia	477.29	3,223.50	2,528.58	1,812.86	3,302.60	2,590.62	1,857.34	3,564.78	2,796.29	2,004.79
Médenine	246.88	1,709.89	1,341.28	961.63	1,763.10	1,383.01	991.55	1,939.45	1,521.34	1,090.73
Monastir	105.04	913.96	716.93	514.00	1,100.77	863.47	619.06	1,724.80	1,352.96	970.01
Nabeul	154.38	1,055.60	828.03	593.66	1,085.02	851.11	610.20	1,170.23	917.95	658.12
Sfax	769.46	5,012.16	3,931.65	2,818.84	5,086.40	3,989.87	2,860.58	5,332.45	4,182.88	2,998.96
Sousse	87.18	591.11	463.68	332.43	611.22	479.45	343.74	722.76	566.95	406.47
Tunis	750.86	5,205.41	4,083.23	2,927.47	5,371.07	4,213.17	3,020.63	5,920.14	4,643.88	3,329.41
Total	**4137.01**	**28,103.35**	**22,044.84**	**15,805.07**	**28,954.87**	**22,712.77**	**16,283.94**	**31,812.92**	**24,954.70**	**17,891.28**

Table A2.2: Assets in the floodplain in the six major coastal cities in Tunisia in 2050 under different SLR scenarios compared and SSPs compared with today's situation.

City	Assets Below H100 [million US$] in 2050									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Bizerte	19.99	137.35	107.74	77.25	141.38	110.90	79.51	154.72	121.36	87.01
Mahdia	144.66	896.26	703.05	504.05	896.89	703.54	504.40	898.98	705.18	505.58
Monastir	49.96	344.92	270.56	193.98	359.73	282.18	202.31	408.83	320.70	229.92
Sfax	426.34	2,674.53	2,097.96	1,504.13	2,685.96	2,106.92	1,510.55	2,723.82	2,136.62	1,531.85
Sousse	46.83	317.18	248.81	178.38	323.41	253.69	181.88	326.74	256.30	183.75
Tunis	629.04	4,292.50	3,367.13	2,414.06	4,411.47	3,460.45	2,480.96	4,805.80	3,769.77	2,702.72

Table A2.3: Assets in the floodplain in 2100 under different SLR scenarios compared and SSPs compared with today's situation.

	Assets Below H100 [million US$] in 2100									
	Today	Low SLR			Medium SLR			High SLR		
Municipality		*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Ariana	247.05	4,897.29	3,197.61	2,051.46	8,059.90	5,262.58	3,376.26	8,059.90	5,262.58	3,376.26
Beja	0.10	1.89	1.24	0.79	10.22	6.67	4.28	10.22	6.67	4.28
Ben Arous	793.65	13,637.49	8,904.37	5,712.70	15,434.42	10,077.65	6,465.43	15,434.42	10,077.65	6,465.43
Bizerte	397.06	7,540.78	4,923.63	3,158.81	10,119.91	6,607.63	4,239.19	10,119.91	6,607.63	4,239.19
Gabés	85.18	1,714.59	1,119.52	718.24	2,829.97	1,847.79	1,185.47	2,829.97	1,847.79	1,185.47
Jendouba	22.88	441.61	288.34	184.99	574.69	375.23	240.74	574.69	375.23	240.74
Mahdia	477.29	8,801.35	5,746.70	3,686.85	12,101.42	7,901.42	5,069.24	12,101.42	7,901.42	5,069.24
Médenine	246.88	4,774.60	3,117.49	2,000.06	7,670.78	5,008.50	3,213.27	7,670.78	5,008.50	3,213.27
Monastir	105.04	4,045.70	2,641.57	1,694.73	14,165.22	9,248.95	5,933.75	14,165.22	9,248.95	5,933.75
Nabeul	154.38	2,891.75	1,888.25	1,211.44	4,989.90	3,258.20	2,090.34	4,989.90	3,258.20	2,090.34
Sfax	769.46	13,225.89	8,635.61	5,540.38	16,979.71	11,086.63	7,112.83	16,979.71	11,086.63	7,112.83
Sousse	87.18	1,760.08	1,149.30	737.36	3,522.31	2,299.92	1,475.55	3,522.31	2,299.92	1,475.55
Tunis	750.86	14,552.55	9,501.84	6,096.00	23,210.81	15,155.11	9,722.92	23,210.81	15,155.11	9,722.92
Total	**4,137.01**	**78,285.56**	**51,115.46**	**32,793.80**	**11,9669.25**	**78,136.26**	**50,129.27**	**119,669.25**	**78,136.26**	**50,129.27**

Table A2.4: Assets in the floodplain in the six major coastal cities in Tunisia in 2100 under different SLR scenarios compared and SSPs compared with today's situation.

	Assets Below H100 [million US$]in 2100									
	Today	Low SLR			Medium SLR			High SLR		
City		*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Bizerte	19.99	380.77	248.62	159.50	407.51	266.07	170.70	425.34	277.72	178.17
Mahdia	144.66	2,246.33	1,466.70	940.98	2,255.06	1,472.41	944.64	2,276.10	1,486.14	953.45
Monastir	49.96	1,001.05	653.62	419.34	1,206.31	787.64	505.32	1,800.74	1,175.76	754.32
Sfax	426.34	6,792.79	4,435.25	2,845.48	6,951.10	4,538.60	2,911.79	7,354.55	4,802.04	3,080.80
Sousse	46.83	815.33	532.36	341.54	829.23	541.43	347.36	869.50	567.72	364.23
Tunis	629.04	11,836.38	7,728.36	4,958.21	13,423.24	8,764.49	5,622.96	18,128.19	11,836.51	7,593.83

Table A2.5: People in the floodplain in 2050 under different SLR scenarios compared and SSPs compared with today's situation.

Municipality	Population Below H100 in 2050									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Ariana	11,379	14,744	16,193	17,819	15,256	16,755	18,437	16,937	18,601	20,468
Beja	5	6	,6	7	6	7	7	7	7	8
Ben Arous	36,555	43,896	48,209	53,049	44,549	48,926	53,838	46,713	51,302	56,452
Bizerte	18,289	23,128	25,400	27,950	23,796	26,134	28,758	26,012	28,568	31,436
Gabés	3,923	5,119	5,622	6,186	5,307	5,829	6,414	5,931	6,513	7,167
Jendouba	1,054	1,344	1,476	1,625	1,386	1,523	1,675	1,526	1,676	1,844
Mahdia	21,984	27,371	30,060	33,078	28,043	30,798	33,890	30,269	33,243	36,580
Médenine	11,371	14,520	15,946	17,547	14,971	16,442	18,093	16,469	18,087	19,902
Monastir	4,838	7,761	8,523	9,379	9,347	10,265	11,296	14,646	16,084	17,699
Nabeul	7,111	8,964	9,844	10,833	9,213	10,119	11,134	9,937	10,913	12,009
Sfax	35,441	42,560	46,741	51,434	43,190	47,433	52,196	45,279	49,728	54,720
Sousse	4,016	5,019	5,512	6,066	5,190	5,700	6,272	6,137	6,740	7,417
Tunis	34,585	44,200	48,542	53,416	45,607	50,087	55,116	50,269	55,207	60,750
Total	**190,551**	**238,632**	**262,074**	**288,389**	**245,861**	**270,018**	**297,126**	**270,132**	**296,669**	**326,452**

Table A2.6: People in the floodplain in the six major coastal cities in Tunisia in 2050 under different SLR scenarios compared and SSPs compared with today's situation.

City	Population Below H100 in 2050									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Bizerte	921	1,166	1,281	1,409	1,200	1,318	1,451	1,314	1,443	1,588
Mahdia	6,663	7,610	8,358	9,197	7,616	8,364	9,204	7,633	8,383	9,225
Monastir	2,301	2,929	3,216	3,539	3,055	3,355	3,691	3,471	3,813	4,195
Sfax	19,637	22,710	24,941	27,445	22,807	25,048	27,562	23,128	25,401	27,951
Sousse	2,157	2,693	2,958	3,255	2,746	3,016	3,319	2,774	3,047	3,353
Tunis	28,973	36,448	40,029	44,048	37,458	41,139	45,269	40,807	44,816	49,315

Table A2.7: People in the floodplain in 2100 under different SLR scenarios compared and SSPs compared with today's situation.

	Population Below H100 in 2100									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
Municipality		***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Ariana	11,379	11,277	15,174	21,367	13,183	17,738	24,977	18,560	24,973	35,165
Beja	5	4	6	8	7	9	12	24	32	45
Ben Arous	36,555	31,404	42,255	59,500	32,671	43,960	61,901	35,542	47,823	67,340
Bizerte	18,289	17,365	23,365	32,900	19,242	25,891	36,458	23,304	31,356	44,153
Gabés	3,923	3,948	5,313	7,481	4,638	6,241	8,788	6,517	8,769	12,347
Jendouba	1,054	1,017	1,368	1,927	1,156	1,555	2,189	1,323	1,781	2,507
Mahdia	21,984	20,267	27,271	38,400	22,791	30,666	43,182	27,867	37,496	52,798
Médenine	11,371	10,995	14,794	20,832	12,693	17,079	24,048	17,665	23,768	33,468
Monastir	4,838	9,316	12,535	17,651	15,311	20,602	29,010	32,619	43,890	61,803
Nabeul	7,111	6,660	8,961	12,618	7,725	10,393	14,635	11,492	15,462	21,772
Sfax	35,441	30,457	40,980	57,705	32,825	44,167	62,193	39,101	52,612	74,083
Sousse	4,016	4,054	5,454	7,680	5,096	6,856	9,654	8,112	10,914	15,368
Tunis	34,585	33,511	45,090	63,492	38,651	52,006	73,230	53,449	71,918	101,268
Total	**190,551**	**180,275**	**242,566**	**341,561**	**205,989**	**277,163**	**390,277**	**275,575**	**370,794**	**522,117**

Table A2.8: People in the floodplain in the six major coastal cities in Tunisia in 2100 under different SLR scenarios compared and SSPs compared with today's situation.

	Population Below H100 in 2100									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
City		***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Bizerte	921	877	1,180	1,661	938	1,263	1,778	979	1,318	1,856
Mahdia	6,663	5,173	6,960	9,801	5,193	6,987	9,839	5,241	7,052	9,931
Monastir	2,301	2,305	3,102	4,368	2,778	3,738	5,263	4,147	5,580	7,857
Sfax	19,637	15,642	21,047	29,637	16,007	21,538	30,327	16,936	22,788	32,088
Sousse	2,157	1,878	2,526	3,557	1,910	2,569	3,618	2,002	2,694	3,794
Tunis	28,973	27,256	36,675	51,642	30,911	41,591	58,565	41,745	56,169	79,093

A3 People flooded annually

Table A3.1: Expected number of people flooded annually per municipality in 2050 under different SLR scenarios compared and SSPs compared with today's situation.

	People flooded annually in 2050									
	Today	Low SLR			Medium SLR			High SLR		
Municipality		SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3
Ariana	7,786	9,716	10,670	11,742	9,962	10,941	12,039	10,825	11,889	13,082
Beja	4	5	5	6	5	5	6	6	6	7
Ben Arous	27,880	35,630	39,130	43,059	36,745	40,354	44,406	40,340	44,304	48,752
Bizerte	13,974	18,059	19,834	21,825	18,689	20,525	22,586	20,808	22,852	25,146
Gabés	2,372	3,351	3,681	4,050	3,539	3,887	4,277	4,163	4,572	5,031
Jendouba	849	1,110	1,219	1,342	1,152	1,266	1,393	1,292	1,419	1,561
Mahdia	15,609	19,663	21,595	23,763	20,217	22,204	24,433	22,128	24,302	26,741
Médenine	7,250	9,519	10,455	11,504	9,964	10,943	12,042	11,439	12,562	13,824
Monastir	3,511	4,541	4,987	5,487	4,714	5,178	5,697	5,432	5,965	6,564
Nabeul	5,440	7,060	7,753	8,532	7,309	8,028	8,834	8,136	8,935	9,832
Sfax	29,362	36,024	39,563	43,537	36,658	40,259	44,302	38,746	42,553	46,826
Sousse	3,051	3,922	4,308	4,740	4,053	4,451	4,897	4,491	4,933	5,428
Tunis	22,810	29,036	31,888	35,090	29,958	32,901	36,204	33,214	36,477	40,139
Total	**139,898**	**177,636**	**195,088**	**214,677**	**182,965**	**200,942**	**221,116**	**201,020**	**220,769**	**242,933**

Table A3.2: Expected number of people flooded annually per city in 2050 under different SLR scenarios and SSPs compared with today's situation.

	People flooded annually in 2050									
	Today	Low SLR			Medium SLR			High SLR		
City		SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3
Bizerte	736	956	1,049	1,155	990	1,087	1,196	1,103	1,211	1,333
Mahdia	5,507	6,869	7,544	8,301	7,027	7,717	8,492	7,453	8,186	9,007
Monastir	1,726	2,207	2,424	2,667	2,277	2,501	2,752	2,515	2,762	3,039
Sfax	18,143	21,739	23,875	26,272	21,841	23,986	26,394	22,162	24,339	26,783
Sousse	1,632	2,094	2,300	2,531	2,162	2,374	2,613	2,384	2,618	2,881
Tunis	19,892	25,278	27,762	30,549	26,058	28,618	31,491	28,737	31,560	34,728

Table A3.3: Expected number of people flooded annually per municipality in 2100 under different SLR scenarios compared and SSPs compared with today's situation.

Municipality	People flooded annually in 2100									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Ariana	7,786	7,224	9,721	13,688	8,622	11,602	16,337	14,242	19,163	26,984
Beja	4	4	5	7	4	6	8	17	24	33
Ben Arous	27,880	26,921	36,223	51,006	30,418	40,928	57,631	33,987	45,731	64,394
Bizerte	13,974	13,845	18,629	26,232	16,315	21,953	30,912	21,036	28,305	39,856
Gabés	2,372	2,750	3,700	5,210	3,456	4,651	6,548	5,417	7,288	10,263
Jendouba	849	858	1,155	1,626	1,016	1,367	1,924	1,265	1,702	2,397
Mahdia	15,609	14,776	19,882	27,996	17,212	23,159	32,611	24,427	32,868	46,282
Médenine	7,250	7,588	10,210	14,376	9,265	12,466	17,554	14,186	19,088	26,879
Monastir	3,511	3,584	4,822	6,790	5,378	7,236	10,189	22,339	30,058	42,325
Nabeul	5,440	5,419	7,292	10,268	6,353	8,549	12,039	9,869	13,280	18,701
Sfax	29,362	26,028	35,022	49,316	28,395	38,207	53,801	35,198	47,361	66,690
Sousse	3,051	2,992	4,026	5,671	3,554	4,781	6,734	6,473	8,710	12,266
Tunis	22,810	22,101	29,738	41,874	26,466	35,611	50,145	41,670	56,068	78,950
Total	**139,898**	**134,090**	**180,425**	**254,060**	**156,454**	**210,516**	**296,433**	**230,126**	**309,646**	**436,020**

Table A3.4: Expected number of people flooded annually per city in 2100 under different SLR scenarios and SSPs compared with today's situation.

City	People flooded annually in 2100									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Bizerte	736	734	988	1,391	860	1,157	1,630	964	1,297	1,826
Mahdia	5,507	5,014	6,747	9,501	5,148	6,927	9,754	5,206	7,005	9,863
Monastir	1,726	1,677	2,256	3,177	1,985	2,671	3,760	3,338	4,491	6,324
Sfax	18,143	14,987	20,166	28,396	15,352	20,656	29,086	16,390	22,053	31,054
Sousse	1,632	1,591	2,140	3,014	1,817	2,445	3,443	1,952	2,626	3,698
Tunis	19,892	19,146	25,762	36,276	22,410	30,154	42,460	33,315	44,827	63,121

A4 Seaflood damages

Table A4.1: Expected damages caused by seafloods under different SLR scenarios compared and SSPs compared with today's situation.

Municipality	Seaflood cost [million US$] in 2050									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Ariana	61.14	436.78	342.62	245.64	454.34	356.40	255.52	513.82	403.05	288.97
Beja	0.02	0.17	0.14	0.10	0.18	0.14	0.10	0.22	0.17	0.12
Ben Arous	191.60	1,424.55	1,117.45	801.15	1,497.02	1,174.29	841.91	1,743.38	1,367.54	980.46
Bizerte	91.60	692.04	542.85	389.19	730.29	572.86	410.71	861.76	675.98	484.64
Gabés	16.14	123.43	96.82	69.41	131.17	102.89	73.77	159.33	124.98	89.60
Jendouba	5.14	39.84	31.25	22.41	42.32	33.20	23.80	50.86	39.89	28.60
Mahdia	119.38	860.81	675.23	484.11	897.45	703.98	504.72	1,022.62	802.17	575.11
Médenine	56.92	410.11	321.70	230.64	428.77	336.34	241.14	496.80	389.70	279.40
Monastir	24.25	180.52	141.60	101.52	189.88	148.95	106.79	223.26	175.13	125.56
Nabeul	34.67	264.68	207.62	148.85	279.89	219.55	157.41	332.06	260.47	186.74
Sfax	245.21	1,722.94	1,351.51	968.98	1,782.95	1,398.58	1,002.73	1,980.16	1,553.28	1,113.65
Sousse	20.50	153.74	120.60	86.46	161.87	126.98	91.04	189.73	148.82	106.70
Tunis	166.90	1,218.47	955.79	685.25	1,275.16	1,000.26	717.13	1,470.81	1,153.74	827.17
Total	**1,033.46**	**7,528.09**	**5,905.18**	**4,233.73**	**7,871.31**	**6,174.42**	**4,426.76**	**9,044.82**	**7,094.93**	**5,086.73**

Table A4.2: Expected damages caused by seafloods in the six major coastal cities in Tunisia under different SLR scenarios compared and SSPs compared with today's situation.

City	Seaflood cost [million US$] in 2050									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Bizerte	4.65	35.54	27.88	19.99	37.62	29.51	21.15	21.15	35.08	25.15
Mahdia	42.31	304.28	238.69	171.13	316.82	248.52	178.18	178.18	280.99	201.46
Monastir	11.97	88.85	69.70	49.97	93.32	73.20	52.48	52.48	85.18	61.07
Sfax	153.27	1,070.87	840.01	602.24	1,104.91	866.71	621.39	621.39	948.88	680.30
Sousse	11.02	82.48	64.70	46.39	86.80	68.09	48.82	48.82	79.64	57.10
Tunis	145.46	1,061.86	832.94	597.18	1,111.09	871.56	624.87	624.87	1,004.11	719.89

Table A4.3: Expected damages caused by seafloods in 2100 under different SLR scenarios compared and SSPs compared with today's situation

Municipality	Seaflood cost [million US$] in 2100									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Ariana	61.14	1,257.29	820.93	526.67	1,527.53	997.38	639.88	2,668.64	1,742.45	1,117.89
Beja	0.02	0.53	0.35	0.22	0.69	0.45	0.29	2.06	1.35	0.86
Ben Arous	191.60	4,246.02	2,772.38	1,778.64	5,300.71	3,461.01	2,220.45	7,840.56	5,119.36	3,284.38
Bizerte	91.60	2,093.92	1,367.19	877.13	2,677.95	1,748.52	1,121.78	4,396.37	2,870.54	1,841.62
Gabés	16.14	385.61	251.78	161.53	519.36	339.11	217.56	995.41	649.94	416.97
Jendouba	5.14	123.11	80.38	51.57	160.88	105.04	67.39	268.26	175.16	112.37
Mahdia	119.38	2,502.88	1,634.22	1,048.45	3,061.82	1,999.17	1,282.59	4,954.14	3,234.72	2,075.27
Médenine	56.92	1,212.02	791.37	507.71	1,535.99	1,002.90	643.42	2,705.02	1,766.20	1,133.12
Monastir	24.25	543.05	354.57	227.48	725.47	473.69	303.90	2,786.79	1,819.59	1,167.37
Nabeul	34.67	807.12	527.05	338.16	1,036.81	677.04	434.40	1,838.86	1,200.77	770.44
Sfax	245.21	4,867.08	3,177.89	2,038.85	5,683.34	3,710.84	2,380.79	8,033.77	5,245.52	3,365.39
Sousse	20.50	462.00	301.65	193.57	586.24	382.77	245.62	1,124.13	733.99	470.97
Tunis	166.90	3,586.51	2,341.75	1,502.38	4,479.33	2,924.70	1,876.37	7,874.16	5,141.30	3,298.46
Total	**1,033.46**	**22,087.13**	**14,421.50**	**9,252.38**	**27,296.13**	**17,822.61**	**11,434.43**	**45,488.19**	**29,700.88**	**19,055.11**

Table A4.4: Expected damages caused by seafloods in 2100 in the six major coastal cities in Tunisia under different SLR scenarios compared and SSPs compared with today's situation.

City	Seaflood cost [million US$] in 2100									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Bizerte	4.65	108.55	70.88	45.47	139.84	91.31	58.58	218.97	142.97	91.72
Mahdia	42.31	878.33	573.49	367.93	1,036.91	677.04	434.36	1,343.92	877.49	562.96
Monastir	11.97	264.80	172.90	110.92	332.94	217.39	139.47	607.22	396.48	254.36
Sfax	153.27	2,981.58	1,946.77	1,248.97	3,370.50	2,200.71	1,411.89	4,251.05	2,775.66	1,780.75
Sousse	11.02	247.39	161.53	103.63	311.12	203.14	130.33	458.34	299.26	192.00
Tunis	145.46	3,122.35	2,038.69	1,307.94	3,875.86	2,530.67	1,623.58	6,522.90	4,259.02	2,732.42

A5 Erosion

Table A5.1: Expected annual beach-nourishment cost in 2050 under different SLR scenarios compared and SSPs compared with today’s situation.

Municipality	Beach nourishment cost annually in 2050 [million US$]									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Ariana	0,00	0,17	0,17	0,12	0,23	0,23	0,17	0,42	0,42	0,31
Beja	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Ben Arous	0,11	0,26	0,26	0,26	0,36	0,36	0,36	0,66	0,66	0,66
Bizerte	0,03	0,50	0,47	0,35	0,70	0,65	0,48	1,28	1,19	0,88
Gabés	0,00	0,42	0,36	0,26	0,57	0,49	0,36	1,05	0,90	0,65
Jendouba	0,00	0,12	0,04	0,02	0,17	0,05	0,03	0,32	0,10	0,06
Mahdia	0,04	0,45	0,33	0,21	0,62	0,46	0,28	1,14	0,83	0,52
Médenine	0,01	0,66	0,55	0,26	0,91	0,76	0,36	1,67	1,39	0,66
Monastir	0,00	0,56	0,49	0,42	0,77	0,67	0,58	1,41	1,24	1,05
Nabeul	0,03	1,50	1,28	0,96	2,07	1,77	1,33	3,79	3,24	2,44
Sfax	0,08	0,22	0,22	0,22	0,30	0,30	0,30	0,55	0,55	0,55
Sousse	0,01	0,45	0,41	0,40	0,62	0,56	0,56	1,14	1,04	1,02
Tunis	0,14	0,30	0,30	0,25	0,42	0,42	0,35	0,77	0,77	0,64
Total	**0,45**	**5,62**	**4,87**	**3,73**	**7,74**	**6,72**	**5,15**	**14,20**	**12,32**	**9,44**

Table A5.2: Expected annual beach-nourishment cost per city in 2050 under different SLR scenarios and SSPs compared with today’s situation.

City	Beach nourishment cost annually in 2050 [US$]									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Bizerte	0	3,1795	31,795	31,795	43,892	43,892	43,892	80,631	80,631	80,631
Mahdia	36,810	6,9624	69,624	69,624	95,910	95,910	95,910	175,740	175,740	175,740
Monastir	0	8,3767	83,767	83,767	115,458	115,458	115,458	211,702	211,702	211,702
Sfax	65,257	12,2430	122,430	122,430	168,700	168,700	168,700	309,221	309,221	309,221
Sousse	0	12,0178	120,178	119,358	165,666	165,666	164,536	303,817	303,817	301,744
Tunis	0	0	0	0	0	0	0	0	0	0

Table A5.3: Expected annual beach-nourishment cost in 2100 under different SLR scenarios compared and SSPs compared with today's situation.

Municipality	**Beach nourishment cost annually in 2100 [million US$]**									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Ariana	0,00	0,18	0,18	0,14	0,40	0,40	0,32	1,31	1,30	1,11
Beja	0,00	0,05	0,00	0,00	0,11	0,00	0,00	0,37	0,00	0,00
Ben Arous	0,11	0,19	0,19	0,19	0,43	0,43	0,43	1,40	1,40	1,40
Bizerte	0,03	0,56	0,42	0,38	1,26	0,94	0,86	4,23	3,32	2,78
Gabés	0,00	0,32	0,31	0,31	0,72	0,69	0,69	2,43	2,24	2,24
Jendouba	0,00	0,25	0,21	0,09	0,56	0,50	0,23	1,82	1,62	0,82
Mahdia	0,04	0,57	0,49	0,35	1,29	1,16	0,78	4,38	3,95	3,03
Médenine	0,01	0,70	0,60	0,53	1,57	1,46	1,19	5,29	5,02	4,10
Monastir	0,00	0,41	0,41	0,41	0,92	0,92	0,92	2,99	2,99	2,99
Nabeul	0,03	1,34	1,23	1,10	3,04	2,91	2,49	9,97	9,45	8,59
Sfax	0,08	0,18	0,18	0,18	0,41	0,41	0,41	1,32	1,31	1,31
Sousse	0,01	0,66	0,58	0,33	1,91	1,37	0,75	6,21	4,45	2,45
Tunis	0,14	0,28	0,25	0,22	0,64	0,57	0,51	2,09	2,01	1,65
Total	**0,45**	**5,69**	**5,03**	**4,23**	**13,28**	**11,75**	**9,58**	**43,82**	**39,07**	**32,48**

Table A5.4: Expected annual beach-nourishment cost per city in 2100 under different SLR scenarios and SSPs compared with today's situation.

City	**Beach nourishment cost annually in 2050 [US$]**									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Bizerte	0	23,325	23,325	23,325	52,827	52,827	52,827	171,671	171,671	171,671
Mahdia	36,810	51,221	51,221	51,221	115,324	115,324	115,324	373,559	373,559	373,559
Monastir	0	61,580	61,580	61,580	138,864	138,864	138,864	450,195	450,195	450,195
Sfax	65,257	90,036	90,036	90,036	202,873	202,873	202,873	657,432	657,432	657,432
Sousse	0	88,330	88,330	88,330	199,263	199,263	199,263	646,151	646,151	646,151
Tunis	0	0	0	0	0	0	0	0	0	0

Table A5.5: Expected annual beach-nourishment volume in 2050 under different SLR scenarios compared and SSPs compared with today's situation.

Municipality	Beach nourishment volume annually in 2050 [m^3]									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Ariana	0	39,635	39,635	24,202	54,716	54,716	33,411	100,515	100,515	61,377
Beja	0	0	0	0	0	0	0	0	0	0
Ben Arous	33,223	42,784	42,784	42,784	59,063	59,063	59,063	108,501	108,501	108,501
Bizerte	7,561	76,849	76,849	67,336	106,089	106,089	92,955	194,890	194,890	170,763
Gabés	0	64,823	64,823	57,646	89,353	89,353	79,460	163,852	163,852	145,710
Jendouba	0	39,705	13,214	7,231	54,859	18,257	9,990	100,881	33,574	18,372
Mahdia	7,092	96,581	75,710	42,604	133,044	104,294	58,689	243,783	191,103	107,539
Médenine	3,158	123,237	94,703	78,045	169,731	130,428	107,485	310,933	238,923	196,894
Monastir	0	87,444	87,444	86,763	120,521	120,521	119,584	220,978	220,978	219,259
Nabeul	8,446	278,476	242,596	197,458	383,883	334,425	272,203	704,002	613,309	499,202
Sfax	21,077	40,811	40,811	40,811	56,234	56,234	56,234	103,076	103,076	103,076
Sousse	3,062	79,605	67,907	67,375	109,737	93,610	92,877	201,248	171,672	170,328
Tunis	23,187	47,033	47,033	47,033	64,929	64,929	64,929	119,276	119,276	119,276
Total	**106,806**	**1,016,982**	**893,510**	**759,288**	**1,402,158**	**1,231,920**	**1,046,881**	**2,571,934**	**2,259,669**	**1,920,298**

Table A5.6: Expected annual beach-nourishment volume per city in 2050 under different SLR scenarios compared and SSPs compared with today's situation.

City	Beach nourishment volume annually in 2050 [m^3]									
	Today	**Low SLR**			**Medium SLR**			**High SLR**		
		SSP5	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***	***SSP5***	***SSP2***	***SSP3***
Bizerte	0	5,299	5,299	5,299	7,315	7,315	7,315	13,439	13,439	13,439
Mahdia	6,135	7,736	7,736	7,736	10,657	10,657	10,657	19,527	19,527	19,527
Monastir	0	9,907	9,907	9,907	13,655	13,655	13,655	25,037	25,037	25,037
Sfax	16,177	20,405	20,405	20,405	28,117	28,117	28,117	51,537	51,537	51,537
Sousse	0	19,893	19,893	19,893	27,423	27,423	27,423	50,291	50,291	50,291
Tunis	0	0	0	0	0	0	0	0	0	0

Table A5.7: Expected annual beach-nourishment volume in 2100 under different SLR scenarios compared and SSPs compared with today's situation.

Municipality	Beach nourishment volume annually in 2100 [m^3]									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Ariana	0	29,974	29,414	29,414	67,884	66,616	66,616	220,602	216,483	216,483
Beja	0	16,892	0	0	38,332	0	0	124,703	0	0
Ben Arous	33,223	31,388	31,388	31,388	71,086	71,086	71,086	231,008	231,008	231,008
Bizerte	7,561	102,990	68,087	56,379	233,278	154,202	127,685	758,135	501,111	414,938
Gabés	0	52,080	47,649	47,649	117,464	107,471	107,471	380,858	348,457	348,457
Jendouba	0	38,569	36,258	29,095	87,558	82,310	66,051	284,903	267,828	214,926
Mahdia	7,092	91,270	81,543	71,053	205,493	183,595	159,975	665,636	594,701	518,193
Médenine	3,158	115,690	112,629	103,993	260,367	253,475	234,031	843,187	820,866	757,881
Monastir	0	64,286	64,286	64,286	144,952	144,952	144,952	469,908	469,908	469,908
Nabeul	8,446	223,871	208,437	205,371	505,019	470,209	463,293	1,637,606	1,524,739	1,502,312
Sfax	21,077	30,458	30,012	30,012	68,630	67,626	67,626	222,404	219,148	219,148
Sousse	3,062	141,014	137,401	58,510	318,113	309,963	131,992	1,031,543	1,005,116	428,009
Tunis	23,187	44,534	44,534	34,505	100,859	100,859	78,146	327,761	327,761	253,950
Total	**106,806**	**983,014**	**891,639**	**761,654**	**2,219,035**	**2,012,363**	**1,718,922**	**7,198,254**	**6,527,126**	**5,575,213**

Table A5.8: Expected annual beach-nourishment volume per city in 2100 under different SLR scenarios compared and SSPs compared with today's situation.

City	Beach nourishment volume annually in 2050 [m^3]									
	Today	Low SLR			Medium SLR			High SLR		
		SSP5	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*	*SSP5*	*SSP2*	*SSP3*
Bizerte	0	3,888	3,888	3,888	8,804	8,804	8,804	28,612	28,612	28,612
Mahdia	6,135	5,691	5,691	5,691	12,814	12,814	12,814	41,507	41,507	41,507
Monastir	0	7,283	7,283	7,283	16,423	16,423	16,423	53,243	53,243	53,243
Sfax	16,177	15,006	15,006	15,006	33,812	33,812	33,812	109,572	109,572	109,572
Sousse	0	14,621	14,621	14,621	32,984	32,984	32,984	106,957	106,957	106,957
Tunis	0	0	0	0	0	0	0	0	0	0

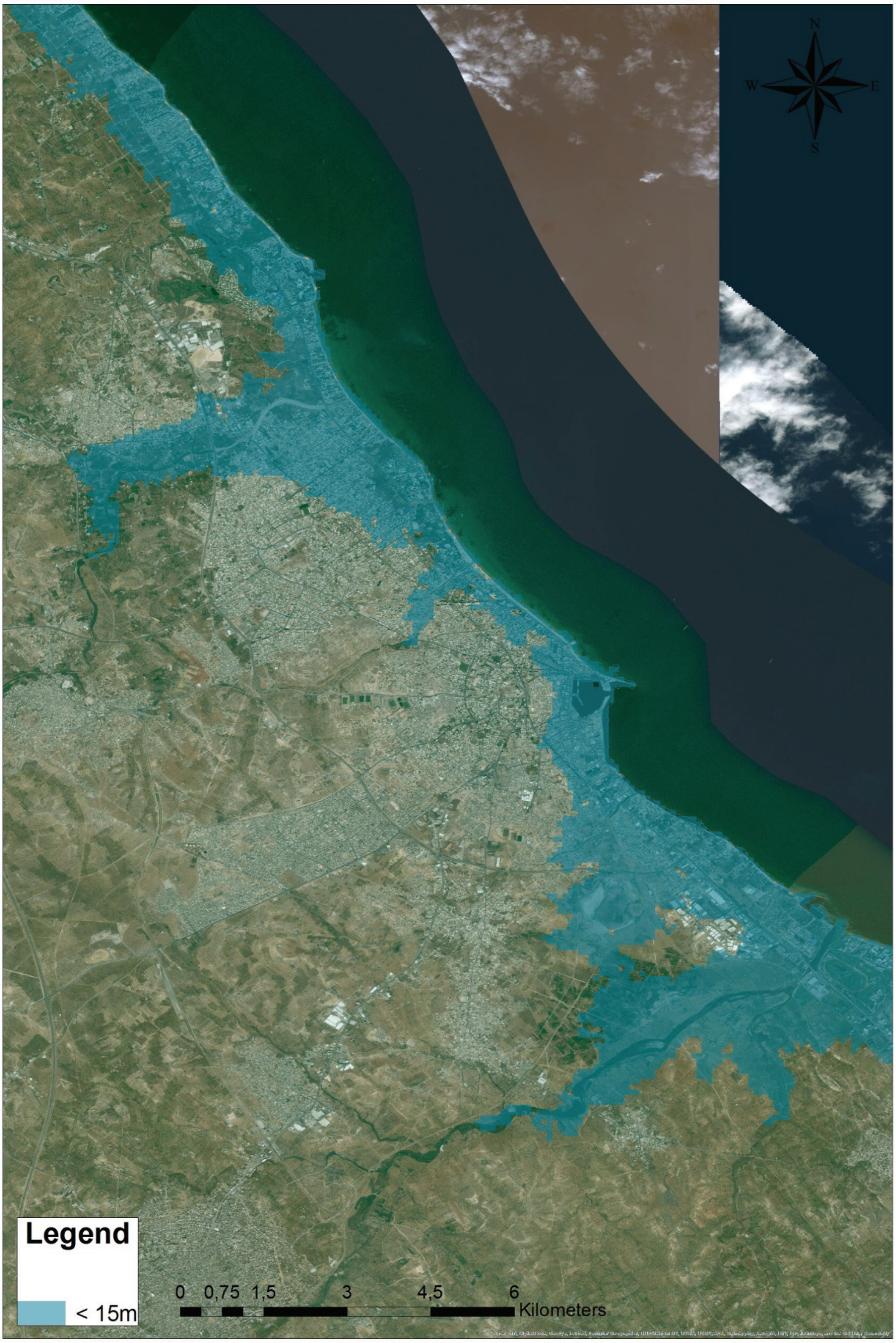
Table A5.9: Total land loss due to direct and indirect erosion in 2050 and 2100 under different SLR scenarios compared with today's situation.

Municipality	**Total land loss due to direct and indirect erosion [m²/year]**						
	Today	**2050**			**2100**		
		Low SLR	***Medium SLR***	***High SLR***	***Low SLR***	***Medium SLR***	***High SLR***
Ariana	7,200	7,506	10,137	18,807	3,360	7,439	24,885
Beja	2,243	2,837	3,919	7,205	2,079	4,718	15,349
Ben Arous	1,793	944	704	1,786	268	426	2,141
Bizerte	17,226	15,927	21,138	39,533	9,745	21,749	72,048
Gabés	8,429	5,089	6,238	12,082	2,446	5,248	18,162
Jendouba	5,624	6,919	9,532	17,551	1,935	4,221	14,440
Mahdia	11,824	11,528	15,392	28,609	3,051	6,471	22,668
Médenine	21,899	20,379	27,008	50,359	10,379	22,849	76,167
Monastir	11,792	6,299	7,484	14,714	3,689	7,956	27,339
Nabeul	41,315	33,450	43,403	81,835	15,733	34,333	116,258
Sfax	7,990	8,236	10,782	20,230	5,653	12,567	41,440
Sousse	18,937	17,256	22,859	42,689	10,967	24,409	80,559
Tunis	3,369	2,695	3,062	6,165	1,510	3,221	11,301
Total	**159,641**	**139,064**	**181,658**	**341,564**	**70,814**	**155,606**	**522,755**

Appendix B: Inundation maps

Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

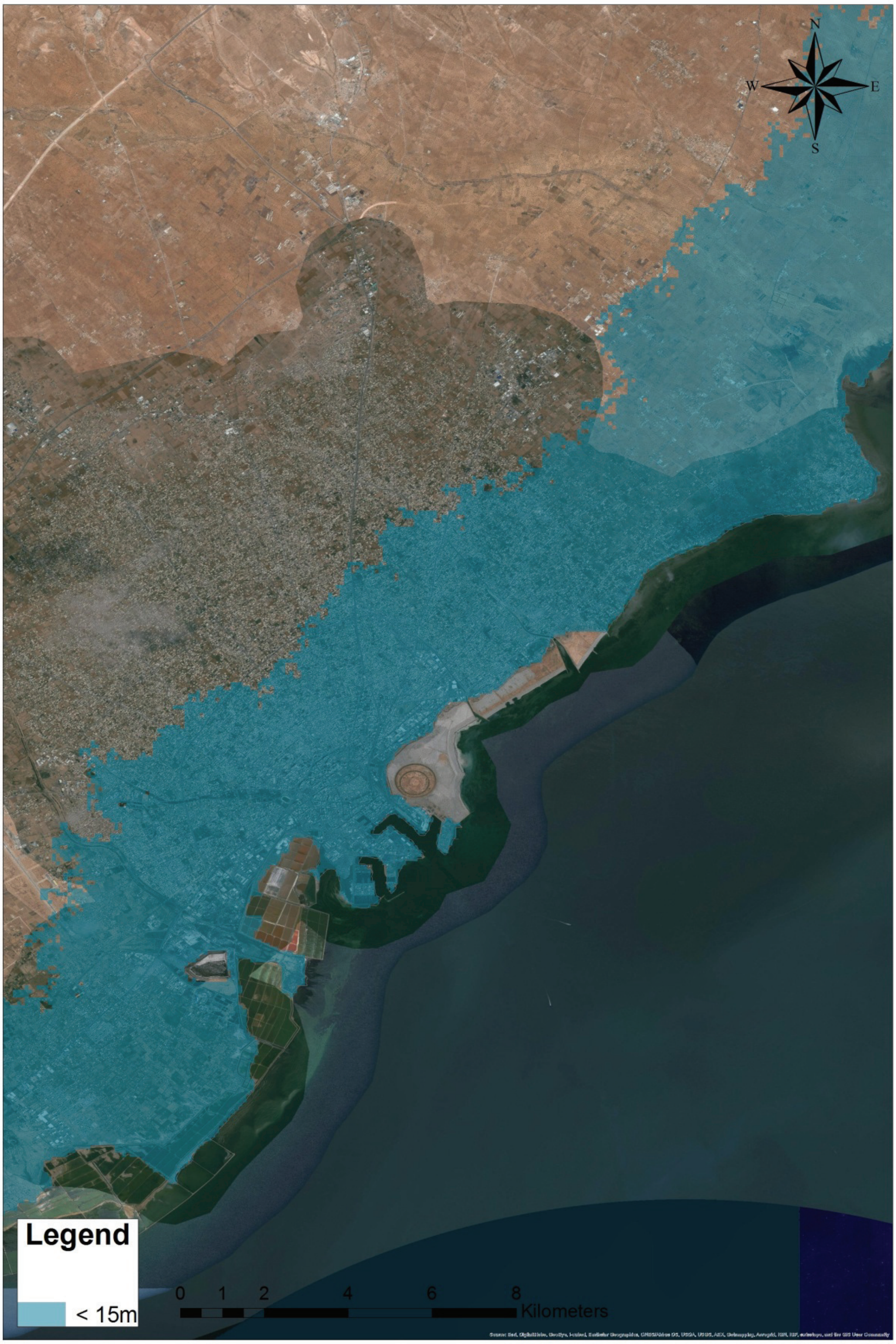
Inundation areas - Soussé



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Inundation areas - Monastir

Inundation areas - Sfax



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Inundation areas - Tunis

Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem
MedPartnership

Together for the Mediterranean Sea
GEF
UNEP
MAP

وزارة البيئة والتنمية المستدامة
Ministère de l'Environnement
et du Développement Durable

APAL
وكالة حماية و تهيئة الشريط الساحلي
AGENCE DE PROTECTION ET
D'AMENAGEMENT DU LITTORAL

PAP/RAC

Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem

MedPartnership

Together for the Mediterranean Sea

GEF UNEP

PAP/RAC is established in 1977 in Split, Croatia, as a part of the Mediterranean Action Plan (MAP) of the United Nations Environment Programme (UNEP). PAP/RAC's mandate is to provide support to Mediterranean countries in the implementation of the Barcelona Convention and its Protocols, and in particular of the Protocol on Integrated Coastal Zone Management. PAP/RAC is oriented towards carrying out of the activities contributing to sustainable development of coastal zones and strengthening capacities for their implementation. Thereby, it co-operates with the national, regional and local authorities, as well as with a large number of international organisations and institutions.

PAP/RAC