Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem

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Strengthening the Knowledge Base on Regional Climate Variability and Change

Application of a Multi-Scale Coastal Risk Index at Regional and Local Scale in the Mediterranean

PLAN BLEU

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List of key abbreviations

CIRCE	Climate Change and Impact Research the Mediterranean Environment
CRI-LS	Coastal Risk Index – Local Scale
CRI-MED	Coastal Risk Index – Mediterranean Scale
CVI	Coastal Vulnerability Index
DSS/DST	Decision Support System / Decision Support Tool
EEA	European Environment Agency
GCM	General Circulation Model
GEF	Global Environment Facility
GIS	Geographic Information System
GFCS	Global Framework for Climate Services
ICZM	Integrated Coastal Zone Management
IPCC	Intergovernmental Panel on Climate Change
MS-CRI	Multi Scale Coastal Risk Index
MedPartnership	Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem
MSSD	Mediterranean Strategy on Sustainable Development
PAP/RAC	Priority Actions Programme / Regional Activity Centre
Plan Bleu/RAC	Plan Bleu / Regional Activity Centre
RACCM	Regional Assessment of Climate Change in the Mediterranean
SDI	Spatial Data Infrastructure

SLR	Sea Level Rise
SST	Sea Surface Temperature
SSPs	Shared Socioeconomic Pathways
SWH	Significant Wave Height
UNEP/GRID	United Nations Environment Programme / Global and Regional Integrated Data Centres
UNEP/MAP	United Nations Environment Programme / Mediterranean Action Plan
WGII	IPCC Working Group II: Impacts, Adaptation and Vulnerability

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Executive Summary

Introduction

The Mediterranean area is particularly affected by adverse consequences of climate variability and change coupled with existing socio-economic processes associated with growing bio-geographical vulnerability and exposure in the coastal areas of the region. As a result, Mediterranean coastal communities and assets are increasingly at risk.

Relevant authorities are encouraged to undertake adaptation measures that are in line with the ICZM (Integrated Coastal Zones Management) Protocol of the Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention) and national ICZM strategies. In this view, UNEP/Mediterranean Action Plan is developing a Regional Climate Change Adaptation Framework aimed at providing enhanced regional coordination. In synergy with a revised Mediterranean Strategy on Sustainable Development, the Regional Framework will assist stakeholders and policy-makers at all levels across the Mediterranean to take action in order to increase the resilience of the coastal natural and socio-economic systems to the impacts of climate change.

In addition, robust scientific methods are needed to assess coastal vulnerability and risks to climate variability and understanding the interaction of climate change with socio-economic and environmental systems is of increasing importance for coastal policy makers in the Mediterranean.

As part of the ClimVar & ICZM Project *"Integration of climatic variability and change into national strategies to implement the ICZM protocol in the Mediterranean"*, the present study is designed to contribute to strengthen the regional knowledge concerning the impacts of climate variability and change on coastal ecosystems and local communities in the Mediterranean.

This study developed and implemented an integrated methodology to assess risk and vulnerability to physical and socio-economic impacts of climate variability and change in the Mediterranean with the aim of identifying coastal hot-spots. The proposed methodology has the potential to assist the involved countries to better assess climate-related risks to their marine and coastal zones by facilitating the analysis of the physical impacts of climate variability and change and the consequences on socio-economic sectors and ecosystems, as well as the identification of strategic adaptation options in the coastal zones of the Mediterranean.

Overview of impacts, vulnerabilities and adaptation options across key coastal sectors in the Mediterranean

Physical changes in the Mediterranean climate have been widely observed and such trends are projected to continue in the future. Major changes are related to an exceptionally high temperature increase compared to the European and global average, in the range of 2 to 6.5 °C by the end of the century (Travers et al., 2010). This is expected to be accompanied by a particularly large decrease in annual mean precipitation especially in summer and an increase in evaporation. A rise of 7 to 12 cm in the overall level of the Mediterranean Sea compared to the past decades is projected by 2050 (Gualdi et al., 2013), with larger sea rise occurring on Eastern and Southern Mediterranean coasts.

Climate change hazards are coupled with existing socio-economic processes associated with growing bio-geographical vulnerability and exposure in coastal areas of the Mediterranean region. One of the primary climate change impacts is on water resources and availability for the main economic sectors. Situations of water scarcity in combination with expected climate change-related phenomena, will lead to reduced runoff and groundwater minimum recharge and consequently to lesser water quality and quantity in some countries. Lower precipitation and increasing temperatures in the Southern and Eastern Mediterranean will exacerbate aridness, land degradation and desertification. Sea-level rise and storm-related floods will make low-lying zones and coastal activities increasingly vulnerable to submersion and beaches vulnerable to erosion. Losses of coastal and marine habitats and ecosystems are also largely implied.

Scientists and practitioners advise that the identification of adaptation actions be made *ad hoc,* based on the assessment of local conditions of impacts and risk/vulnerability and the analysis of costs and benefits of options to adapt. Consolidated inventories of possible adaptation measures, such as those accessible through the European portal Climate-ADAPT, OURCOAST database as well as the Mediterranean Integrated Climate Information platform (MedICIP), can offer inspiration when planning for adaptation, although this is no substitute for developing *ad hoc* responses.

Regional Risk Assessment: Implementation of the Multi-scale Coastal Risk Index in the Mediterranean (CRI-MED)

In its 2014 Fifth Assessment Report, Working Group II of the IPCC (Intergovernmental Panel on Climate Change) introduced innovative elements with respect to the past approach to support decision-making in the context of climate change. Greater emphasis is now put on risk, while the concept of vulnerability is seen as a factor contributing to it. Here, *risk* of climate-related impacts results from the interaction of *climate-related hazards* with the *vulnerability* and *exposure* of human and natural systems. Hazards are hazardous events and trends linked to both natural climate variability and climate change. Vulnerability and exposure are the result of socio-economic pathways and societal conditions, including adaptation and mitigation actions. Changes in both the climate system and socio-economic processes are central drivers of the different core components (vulnerability, exposure, and hazards) that constitute risk. According to IPCC, risks are considered "key" when societies and systems exposed are impacted by high hazard or characterized by high vulnerability, or both (IPCC, 2014).

As an outcome of this study, a multi-scale coastal risk index has been developed on the basis of the Multi-scale Vulnerability Index (McLaughlin and

Cooper, 2010) by integrating the revised IPCC approach and focusing on risk. The Coastal Risk Index applied to assess risk related to climate variability and change at the regional scale in the Mediterranean area is called CRI-MED.

The CRI-MED index is composed of three sub-indexes:

- *Coastal Forcing*, characterizing the variables related to climate hazards (storms, drought, sea-level rise) and non-climate forcing (population growth, tourist arrivals);
- *Coastal Vulnerability*, integrating the resilience variables (age of population, level of education) and coastal susceptibility variables (landform, elevation);
- *Coastal Exposure*, describing coastal targets potentially at risk, the exposure (land cover, population density).

The selected variables contribute in a different way to the risks affecting Mediterranean coastal zones and must be weighted accordingly for an accurate calculation of CRI-MED. For the purposes of this study, sea level rise, storminess, as well as landform and elevation of coasts are considered to play the most significant role in generating coastal risk.

The CRI-MED method was applied regionally to measure risk in the eleven countries involved in the project ClimVar & ICZM, namely Albania, Algeria, Bosnia and Herzegovina, Croatia, Egypt, Libya, Montenegro, Morocco, Palestine, Syria and Tunisia.

The application led to a ranking of the relative risk of each coastal region in relation to potential coastal hazards generated and/or exacerbated by climate and non-climate forcing.

In the CRI-MED study, the risk equation with weighted variables was applied to each cell (300m X 300m) of the coastal study area grid for a total of 52.350 cells. The coastal spots at risk were identified through a statistical analysis by spatially clustering cells characterized by similar risk values. To be considered a statistically significant hot-spot, a site (cell) must be characterized by a "high-risk" value and be surrounded by other sites (cells) with high risk values as well.

The statistical analysis resulted in a very limited presence of cells characterized by relatively high risk values that could form clusters. CRI scores (CRI≥0.55) were deemed to identify hot-spots. The hot-spot threshold was set in a way to highlight only areas that appear *exceptionally* at risk according to the statistical distribution of cells.

The resulting Regional Risk Assessment Map of coastal risk to climate and non-climate forcing, displays the output of the analysis in terms of qualitative risk classes in the coastal zones investigated. The map shows the values of risk assumed by each location (cell) by applying the equation defined for the method CRI-MED. Sites that assume "extremely high risk" values are indicated in red and in the context of the study these are defined as "hot-spots".

Noting that areas at extremely high risk are relatively few and predominantly located in the southern Mediterranean region, the countries primarily concerned by coastal risk include Morocco, Algeria, Libya, Egypt, Palestine, and Syria. A list of identified national coastal hot-spots was compiled for these countries.

The risk assessment approach used in this study highlights some substantial differences with traditional vulnerability assessment methods. Risk depends on the interaction of vulnerability, forcing and exposure. If vulnerability is high but forcing and/or exposure are low, risk is low.

The main lesson emerged from the regional risk assessment based on CRI-MED is that hot-spots are also areas of extremely high vulnerability. But at the same time, not all areas presenting extremely high vulnerability can be considered hot-spots, as the related values of forcing and exposure range from extremely low to moderate.

Local Risk Assessment: Implementation of the Multi-scale Coastal Risk Index in Morocco (CRI-LS)

The multi-scale coastal risk index for the risk assessment was applied at the local spatial scale and called CRI-LS. Tetouan, Morocco, already identified as a hot-spot in the CRI-MED assessment was selected as a case study.

The application of the CRI-LS led to the identification of three coastal hot-spots located in the Tetouan flood plains (Restinga Plain, Smir plain, Martil Alila Plain).

Some differences exist between the two scales of application of the coastal risk indexes developed in this study (CRI-MED vs. CRI-LS). These include the definition of the coastal unit based on the coastal hazard zone, and the choice of variables used to describe the three sub-indexes. Moreover, higher resolution is required at the local scale. In fact, in order to obtain more detailed information to plan appropriate strategies, more variables were introduced for the sub-indexes of vulnerability and exposure, while the variables of the forcing sub-index remained the same as for the CRI-MED.

Conclusions

The multi-scale coastal risk index methodology, proposed for the regional and local coastal risk assessment respectively through the application of the CRI-MED and the CRI-LS indexes, allows a scientifically sound detection of the coastal hot-spots. These tools seem particularly valuable to support decision-makers in the spatial identification of the coastal areas characterized by different vulnerability and exposure levels and in the definition of adaptation options.

The main advantages of multi-scale coastal risk index methods include the following:

- Non expensive and easy calculation process;
- Consideration of physical as well as socio- economic variables;

- Presence of three separated sub-indices representing vulnerability, exposure and forcing;
- Possible expansion of the index to include additional data sets;
- Integration of the risk concept as proposed by IPCC AR5;
- Risk and vulnerability maps can also be produced;
- Potential for replicability and application at various scales.

On the other side, these methods imply challenges when weighting the variables, since this choice will ultimately affect the visualization and interpretation of results.

These tools can be improved and expanded in many ways. For instance, the involvement of an expert panel to assign weights to the variables of CRI-MED can improve the accuracy of the methodology. Also, providing non-experts with the ability to alter the weights can be valuable. The tool can be used interactively to enable politicians, decision-makers and the wider public to see how changes in weighting affect the index.

Finally, methodological improvements can be obtained by increasing the number of variables for the sub-indexes and defining more accurate geo-referenced standardized databases validated at the regional/local level.

Introduction

Background

The Mediterranean region, populated by over 500 million people spread across about 30 countries in Africa, Asia and Europe, has long been recognised as one of the areas most responsive to climate change and indicated as a typical "hot-spot" (IPCC, 2001; Giorgi, 2006).

Climate variability and change are becoming increasingly evident in the area according to the most recent studies referenced by IPCC in its Fifth Assessment Report (IPCC, 2013) and the SREX Report (IPCC, 2012), as well as the European Environment Agency (EEA) in its latest indicators assessment (EEA, 2014). The expected impacts of climate change make the whole region especially vulnerable (Navarra and Tubiana, 2013 a b c; IPCC, 2014), mainly in relation to conditions of water scarcity, concentration of population, economic activities and infrastructure in coastal areas, and reliance on climate-sensitive agriculture (EEA, 2015a).

Against this backdrop, analyzing and understanding how variability and change affect Mediterranean climate conditions not only have vast scientific relevance, but also are meant to serve significant social and economic interests. Further investigating the role of climate and non-climate drivers on the Mediterranean coastal zones is vital to understand the underlying risks and identify appropriate response measures.

Integrated Coastal Zone Management (ICZM) is a process of adaptive management of resources to ensure sustainable development of coastal areas, which aims to prepare a cross-connection between the various policies that have an impact on coastal regions and which is implemented through the planning and management of coastal resources and space. To this end, it requires the involvement of all policy makers at local, regional, national and supranational level, and more generally all those whose activities have an impact on, or are impacted by the coastal zone (coastal stakeholders). ICZM also aims to promote the economic and social wellbeing of coastal areas and enable them to ensure the welfare of the communities who live there. In coastal areas, these socio-economic and environmental objectives are intimately and inextricably linked.

The Protocol on ICZM in the framework of the Barcelona Convention[1] aims at promoting a common framework for the integrated management of the coastal areas of the Mediterranean. The Protocol, signed in Madrid on 16 January 2009, entered into force March 24, 2011. Article 8 of the ICZM Protocol, as an international agreement, contains the legally binding commitment to establish a setback zone where construction is not allowed, applicable to the entire coastal area, while providing a mechanism for adaptation to this principle. The definition of setback areas will consider risks affecting the coastal zone, including risks arising from the likely effects of climate change on current and future (such as the risk of flooding by rising sea levels, erosion, etc.) in order to develop policies for the management of changing natural hazards and their consequential impacts.

Planning adaptation in coastal zones is not an easy process because of the uncertainties due to climate change projections, in particular sea level rise (SLR) projections in the Mediterranean, and the uncertainties associated to the possible impacts. Despite these uncertainties, the acceleration of the impacts of global warming that emerges from the IPCC Fifth Assessment Report (IPCC, 2014) makes it even more challenging to design effective adaptation measures.

These uncertainties demand a high degree of flexibility to adapt to climate and non-climate driven changes and in this sense designing and

[1] Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean. Adopted in 1976. The so-called Barcelona Convention includes 7 Protocols addressing specific aspects of the Mediterranean environmental conservation, including a Protocol on Integrated Coastal Zone Management.

implementing a robust method to assess current and future vulnerabilities risks to coastal hazards is a challenging issue for research (Sahin, 2011) and for decision-makers.

Scientific robust methods are needed to assess coastal vulnerability and risks to climate variability and understanding the interaction of climate change with socio-economic and environmental systems is of increasing importance for coastal policy makers in the Mediterranean.

Coastal vulnerability and risk factors must be taken into consideration in the coastal development planning and management approval process that is driven by a mutually reinforcing interaction of local population, conservation and private sector development. Public and private players involved in coastal issues should improve the way they use information on the climate, i.e. should integrate it more into their policies, development plans, business plans. Coastal policy makers need to include a wide range of stakeholders and the general public within the decision-making process through consultation but "this task remains difficult because of the dynamic complexity of coastal systems and the impediments involved in communicating this to a lay audience" (Brown, 2006). The use of visualization techniques (e.g. risk maps) provide a means to improve this knowledge transfer procedure and promote wider community inclusion within the decision-making process (Al-Kodmany, 2001; Orland, Budthimedhee and Uusitalo, 2001).

The ClimVar & ICZM Project

The present report was developed in the framework of the ClimVar & ICZM Project "Integration of climatic variability and change into national strategies to implement the ICZM protocol in the Mediterranean".

The ClimVar & ICZM Project is a complementary project to the overall GEF/UNEP/World Bank Strategic Partnership for the Mediterranean Sea Large

Marine Ecosystem (the MedPartnership) initiative.[2] It is a collective effort executed in eleven of the Mediterranean countries in order to promote the use of Integrated Coastal Zone Management (ICZM) as an effective tool to deal with the impacts of climate variability and change in coastal zones.

The objective of the ClimVar & ICZM Project is to create an enabling environment for the integration of climate variability and change coping strategies into ICZM policies, plans and programmes of Mediterranean countries by:

- Strengthening the understanding of the impacts of climate variability and change on the coastal zones of the Mediterranean region; and
- Establishing the needed information exchange mechanisms, capacity and regional pilot experiences.

This study contributes to one of the main objectives of the ClimVar & ICZM Project, namely to strengthen the knowledge on regional impacts of climate variability and change and to define their specific characteristics in the Mediterranean region.

The development of this study was closely linked with that of relevant policy and institutional processes in the Mediterranean under the auspices of the United Nations Environment Programme Mediterranean Action Plan (UNEP/MAP) of the Barcelona Convention, including the development and adoption of the **Regional Climate Change Adaptation Framework in the Mediterranean**[3] and the revision of the **Mediterranean Strategy on Sustainable Development (MSSD)**[4]**.** This is expected to place more emphasis on emerging priorities such as adaptation to climate change, with

[2] The ClimVar & ICZM Project is led by UNEP/MAP and is financially supported by the GEF and all participating countries, executing agencies and donors.

[3] The preparation of the Framework has started in 2010 by UNEP/MAP Secretariat. The draft Framework is going to be submitted for consideration by the 19th meeting of the Contracting Parties of the Barcelona Convention (COP19) that will be held in February 2016 in Greece.

[4] In their 18th Ordinary Meeting held in Istanbul, Turkey (December, 2013), the Contracting Parties to the Barcelona Convention requested UNEP/MAP Secretariat to launch the process of the review of the MSSD adopted in 2005 with a view to submitting a revised MSSD for consideration and adoption by the Contracting Parties in their 19th Meeting (COP19). The revision of the MSSD (2016-2015) started in late 2014 and aims at including climate change as one of its 6 Focus Areas.

the aim to provide those processes and the involved national and international stakeholders with updated information and data on climate-related risks, vulnerabilities and adaptation actions in the region.

Scope and objectives of this report

As part of the ClimVar & ICZM Project presented above, this study is designed to contribute to strengthen the regional knowledge concerning the impacts of climate variability and change on coastal ecosystems and local communities in the Mediterranean.

The geographical scope of this report encompasses the coastal areas of eleven Mediterranean countries identified by the ClimVar & ICZM Project. These include Algeria, Albania, Bosnia and Herzegovina, Croatia, Egypt, Libya, Morocco, Montenegro, Palestine, Syria and Tunisia.

The main goal of this study is to develop an integrated methodology to identify "climate hot-spots" along the Mediterranean coastline.

The study has the primary goal of developing the most appropriate methodology to detect coastal "climate hot-spots" in the countries involved in the project. The proposed methodology has thus the potential to assist these countries to better assess climate-related risks to their marine and coastal zones by facilitating the analysis of the physical impacts of climate variability and change and the consequences on socio-economic sectors and ecosystems, and allow the identification of strategic adaptation options in the coastal zones of the Mediterranean.

Specifically, the study aims at achieving six research objectives:

1. Providing a regional and sub-regional overview of vulnerable key socio-economic sectors (qualitative analysis).
2. Exploring relevant options of adaptation for coastal zones in the region (qualitative analysis).
3. Taking stock of existing relevant tools and methodologies at regional, sub-regional and local level to evaluate vulnerability and risk to the impacts of climate variability and change (qualitative analysis).
4. Developing an integrated methodology for the regional, sub-regional and local vulnerability and risk assessment of physical and socio-economic impacts of climate variability and change.
5. Delivering a regional analysis of expected impacts of climate variability and change, which allows to calculate vulnerabilities and risks and identify coastal hot-spots (quantitative analysis).
6. Delivering a targeted analysis of expected impacts of climate variability and change in one relevant local case study (quantitative analysis).

The outcomes of this study will inform the development of the Regional Climate Change Adaptation Framework in the Mediterranean as well as the revision of the MSSD, with a view to promote the use of ICZM in the participating countries as an effective tool to deal with the impacts of climate variability and change in coastal zones by mainstreaming climate issues into national development policies and disaster risk reduction strategies.

Report outline

The report is articulated in different sections that address the specific research objectives of the study.

Section 1 provides an introductory overview of the main features of the Mediterranean climate variability and change, including of climate change impacts, vulnerabilities and adaptation in the region with a focus on four main socio-economic coastal sectors.

The core of this research work is represented by Section 2 and 3 where the concept, construction and application of the proposed methodology at different scales are comprehensively presented.

Section 2 introduces the selection and fine-tuning of the methodology used to perform the regional risk assessment, and the subsequent implementation of a Multi-Scale Coastal Risk Index at the Mediterranean scale.

Section 3 presents the methodology used for the local risk assessment and the implementation of the Multi-Scale Coastal Risk Index at the local scale in the case study of Tetouan, Morocco.

The Conclusions offer a synthesis of the key findings for the use of coastal stakeholders community. Recommendations for future research initiatives are also put forward.

In the Annexes, relevant outcomes of the analysis including country risk maps are available.

Methodological approach

The primary task of the present study is to develop and implement an integrated methodology to assess risk and vulnerability to physical and socio-economic impacts of climate variability and change in the Mediterranean with the aim of identifying coastal hot-spots.

In a preliminary phase of this study, the most suitable methodology for carrying out an assessment of climate risk and vulnerability at the regional and local scale was selected among a family of tools that can be applied at several scales (local, sub-regional and regional) to assess climate risk and vulnerability, which were identified and evaluated against a number of criteria. The methodology chosen as the basis for our work is the Multi-Scale

Coastal Vulnerability Index (CVI) developed by McLaughlin and Cooper (2010).

> ***The integrated methodology applied in this study is a Multi-Scale Coastal Risk Index (MS-CRI).***
>
> ***It is called CRI-MED for the regional scale in the Mediterranean and CRI-LS for the local scale.***

In the next phase the selected methodology was adjusted to meet the needs of the ClimVar & ICZM Project, and integrating the concept of "risk" according to the most recent scientific findings. The conceptual framework for risk and vulnerability used in this study makes reference to the recently published IPCC WGII AR5 (IPCC, 2014) which mainly focuses on risk. For this reason we discuss of a coastal risk index instead of a coastal vulnerability index. As such, the integrated methodology we propose in this study is based on a Multi-Scale Coastal Risk Index (MS-CRI) that can be applied both at regional and local scale to assess risk related to climate variability and change in the coastal areas.

The geographical coverage of the study encompasses the coastal zones of the participating countries, which correspond to the field of application of the ICZM Protocol of the Barcelona Convention as defined by Article 3 of the Protocol.[5]

The limitation of the "coastal zone" is a national matter and it has been largely discussed at the Mediterranean level with the aim to identify a common unit for regional studies and analyses. Currently there is no shared

[5] "Coastal zone" means the geomorphologic area either side of the seashore in which the interaction between the marine and land parts occurs in the form of complex ecological and resource systems made up of biotic and abiotic components coexisting and interacting with human communities and relevant socio-economic activities.

definition of coastal unit to be used for regional analyses. A characterization of the spatial unit was therefore specifically proposed by this study, which implies the vulnerability analysis to be carried out in the coastal stretch of the eleven Mediterranean countries for a length of 18.789 km and a width of 250 m.

In order to apply the MS-CRI at the regional level (CRI-MED), a collection of data for the variables used in the CRI-MED sub-indexes (Exposure, Vulnerability, and Forcing) was carried out based on available databases (e.g. AVISO Satellite Altimetry, Land Cover (LC) of the Climate Change Initiative, The World Bank database, etc.). The application of the CRI-MED resulted in a series of regional and national risk maps highlighting potential coastal hot-spots in the whole Mediterranean basin and for each of the eleven involved Mediterranean countries. The identified hot-spots are not investigated in-depth within the current research as such analysis was deemed to require a dedicated effort that is beyond the scope of this study.

The integrated methodology developed for the local scale (CRI-LS) was applied to a case study for the targeted analysis of physical and socio-economic impacts of climate variability and change in one of the participating countries (Tetouan, Morocco).

An overview of impacts, vulnerabilities across socio-economic sectors as well as the exploration of adaptation options were carried out based on existing literature with a regional and sub-regional focus when information was available. Emphasis is put on few sectors of interest for the Mediterranean countries involved in this study, namely: Food production, Transport Infrastructure, Tourism and Water Management.

Relevant knowledge base and stakeholders

While putting forward an innovative application of a well-established risk assessment methodology, the overall research largely builds upon the various studies carried out under the ClimVar & ICZM Project as well as the outcomes of other existing relevant regional and sub-regional projects, and adopts methods and tools that are recognized as being appropriate and beneficial to assess climate variability and change in the Mediterranean area.

For the success of this study, it was considered critical to design and implement the task hand-in-hand with ClimVar & ICZM Project partners,[6] experts and decision-makers from the participating governments and other types of organisations who make climate-sensitive decisions in coastal areas and could benefit from this project. The inception phase involved extensive consultations with ClimVar & ICZM Project partners and led to the refinement of the initial research proposal. The consultations contributed to narrow down the focus the work on the regional assessment and avoid duplication of efforts among activities taking place at a more local scale within the whole ClimVar & ICZM Project.

In the course of the study, carried out between October 2014 and April 2015, the draft outcomes were presented to the scientific community in various occasions including at the meetings of the Advisory Panel to the Regional Climate Change Adaptation Framework in the Mediterranean held in Athens[7] and the Conference on the Review of the MSSD held in Malta.[8]

Relevant national stakeholders such as MedPartnership and ClimVar National Focal Points were engaged in consultations on the draft report between April and May 2015.

[6] The ClimVar & ICZM Project is led by UNEP/MAP. The executing partners of the project are: Plan Bleu/RAC, PAP/RAC, and GWP-Med.

[7] The First and Second meetings of the Advisory Panel were held on 18 December 2014 and 11-12 March 2015 in Athens, Greece.

[8] The Conference on the Review of the MSSD was held on 17-18 February 2015, Malta.

Overview of impacts, vulnerability and adaptation across key coastal sectors in the Mediterranean

In this section

This section provides a summary of the impacts of climate variability and change on vulnerable socio-economic sectors at the regional level based on the available scientific literature with focus on Europe and the Mediterranean. Furthermore, an overview of adaptation options for coastal areas of the Mediterranean is drawn from existing literature. Some of the major socio-economic sectors of the Mediterranean such as Food production, Transport Infrastructure, Tourism and Water Management are prioritised in the analysis as they represent keys areas of interest for the countries involved in the ClimVar & ICZM Project.

In particular, the outcomes of the studies carried out by PAP/RAC under the ClimVar & ICZM Project, including assessments in demonstration sites that were made available in the course of the research are integrated in the present work.

Moreover, the findings of the EU FP6 project CIRCE[9] were taken into primary consideration for this research. CIRCE provided the first evaluation of climate change impacts in the area, producing an extremely comprehensive report – Regional Assessment of Climate Change in the Mediterranean (RACCM),

[9] CIRCE – Climate Change and Impact Research: the Mediterranean Environment: http://www.circeproject.eu

tailored specifically for decision-makers dealing with mitigation and adaptation strategies in the Mediterranean environment (Navarra and Tubiana, 2013 a b c).

Main features of climate variability and change in the Mediterranean

The climate of the Mediterranean region is affected by the interaction between mid-latitude and sub-tropical regimes and the composite morphology of mountain chains and land-sea contrast (Gualdi et al., 2013). The Mediterranean Sea is a marginal sea; the system Mediterranean/Black Sea has a semi-enclosed nature, connected to the Atlantic Ocean through the Strait of Gibraltar. The region is situated in a transitional zone with a complex morphology which makes the Mediterranean basin comparable to a lake with high peninsulas and mountain barriers.

The climate in the Mediterranean region is therefore characterized by unique conditions: wet winters and dry summers with large variation during the year in rainfall and frequent droughts and dry spells, which implies considerable consequences in the water cycle. Increases in evaporation from the sea and in freshwater evaporation from the land have great impacts on salt, water and energy budgets and directly affect Mediterranean Sea salinity, sea level and circulation, the latter dominated by large-scale cyclonic gyres. Forced flow between the gaps of mountain regions and thermal circulation at the local and regional scale, locally, influence the meteorology (Gualdi et al., 2013). The region is characterized by a large gradient, due to the interaction between two systems: the North Atlantic anticyclone and the low-pressure system over the Indian Ocean and the Middle West. The water exchange with the Atlantic Ocean in the strait of Gibraltar controls the heat and the water budget for the Mediterranean basin. The heat gained by advection, through the strait of Gibraltar, is lost during the winter in the area, that is affected by northerly continental winds. Thus the wind regime is very important in the heat budget. In addition, during winter, cyclonic disturbance causing wind storm influences the climate in the Mediterranean (Gualdi et al., 2013).

Observed and projected changes in climate

Average annual air temperature is increasing in the whole Mediterranean region and such increase is estimated to be slightly higher than at the world level (Hallegatte et al., 2007) with a projected value in the range 2 °C - 6.5 °C by the end of the century (Travers et al., 2010). According to the findings of the project CIRCE, the change of near-surface temperature in the recent past is coherent with the observations, which proves that the Mediterranean region was affected by exceptional warming during the 20th century. From 1951 to 2000, the mean heating tendency was 0,1 °C ± 0,04 °C/decade.

Sea level rise (SLR) is also an issue of concern according to the recent EEA indicators assessment (EEA, 2014)[10], with some regions of the Mediterranean basin showing increasing trends of more than 6 mm/year, and others showing decreases of more than 4 mm/year in absolute sea level from 1992 to 2013 as observed by satellites, against a global mean of about 3 mm/year over the last two decades. As for projections of future changes in the level of the Mediterranean Sea in the first decades of the XXI century, the IPCC reports projections of SLR in the range of 0.1–0.3 m by 2050 and of 0.1–0.9 m by 2100, with major impacts on the southern Mediterranean region (IPCC, 2013). The simulations conducted by the project CIRCE (Navarra and Tubiana, 2013 a) based on the A1B IPCC emission scenarios, predict an increase in the overall level of the Mediterranean Sea ranging between around 7-12 cm in the period 2021-2050 (Gualdi et al., 2013).[11] As sea surface temperature (SST) increase and hydrologic budget variations affect sea density with consequences on the sea level, SLR in the Mediterranean is

[10] In general terms EEA past sea-level trends across Europe are reported in two different ways: 1) absolute sea level change based on satellite altimeter measurements that reflect primarily the contribution of global climate change to sea-level rise in Europe; 2) relative sea-level change based on tide gauges which takes into account isostatic movement. The satellite measures only consider eustatic changes.

[11] Compared to the reference period 1961-1990.

mainly due to a steric effect of 0.29(±0.13) cm/year. It should be noted that in this case scientific uncertainty is particularly high, as making multi-decadal regional projections for relatively small isolated and semi-isolated basins such as the Mediterranean is more complex than for the global ocean (EEA, 2014).

Nevertheless, the effect of SLR is considerable in most low-lying coasts of the Mediterranean basin where communities and infrastructure are typically located.

In addition to the seawater expansion due to steric effect, coastal subsidence and global ocean level increase induced by continental glaciers melting (in Greenland and West Antartica) have to be considered as SLR components for the Mediterranean.

The change in the precipitation pattern points out a tendency to a dry condition, particularly during the summer season. Overall, the decrease in rainfall in the period 2021-2050 is expected to be around 5% (Gualdi et al., 2013). The precipitation and temperature tendency as evaluated in the CIRCE project are associated to the largest change in the Mediterranean basin and its hydrologic cycle. The balance evaporation-precipitation shows a positive sign in the sea and neighbouring land, which explains the increase in evaporation and the decrease in precipitation.

The projections of extreme storm surges (storminess) for the Mediterranean basin are not univocal. According to existing studies, climate change presents a small effect on marine storms and "suggest weaker marine storms in future scenarios than in the present climate" (Gualdi et al., 2013). Some speak of a decrease in the frequency of storms towards the eastern part of the Mediterranean (Busuioc, 2001), but also an increase in storminess for parts of the Adriatic and Aegean Sea (Guedes Soares et al., 2002). A study by Marcos et al. (2011) projected a reduction in both the number and frequency of storm surge events during the XXI century in the Mediterranean basin. More recently, Conte and Lionello (2014) investigated the effects of climate change on storms integrating studies carried out in several Mediterranean coastal zones based on a new set of climate simulations and datasets produced in the CIRCE project. Their analysis confirmed that "storm surges extremes are little affected by climate change with changes within the ±5% range" (Conte & Lionello, 2014). Nevertheless marine storms and related storm surges can represent a major issue at the level of local scale for the assessment of coastal risk. The uncertainty in the likelihood of disastrous events is one of the main issues for vulnerability assessment and managing hazards related to future marine storms (Gualdi et al., 2013).

Key observed and expected physical changes in the Mediterranean climate:

- ***Temperature increase higher than the European and global average***
- ***Exceptional decrease in annual mean precipitation especially in summer***
- ***Increase in evaporation***
- ***Larger SLR on the southern Mediterranean region.***

Expected physical and environmental impacts

According to the results of the project CIRCE and in line with the studies referenced in the relevant assessments published by EEA in the last years for the whole European region (EEA, JRC & WHO, 2008; EEA, 2010; EEA, 2012; EEA, 2015b), a wide range of observed impacts and bio-geographical vulnerabilities associated to climate change characterize coastal areas in the Mediterranean region.

The main physical impacts of climate change in the Mediterranean Sea region are related to changes in SST and precipitation, changes in the water budget, changes in the regional heat budget and SLR (Rahmstorf, 2012).

Mediterranean coastal regions show exceptional biodiversity compared to any other region of the world. Such areas are home to a great number of endemic species that are considered vulnerable to climate change. Unusually high air or water temperature have already led to mass mortalities of marine organisms, for example, gorgonians in the northwestern Mediterranean (Garrabou et al., 2009). Coupling of downscaled model projections using the SRES A1B scenario in the western Mediterranean with relationships between mortality rates and maximum seawater temperature led Jordá et al. (2012) to conclude with high confidence that seagrass meadows may become functionally extinct by 2050–2060. It is also virtually certain that poleward range shifts in vegetated coastal habitats will continue with climate change (in Wong et al., 2014).

It is worth highlighting the research carried out within the project CIRCE that was devoted to the evaluation of the vulnerability of ecosystem services in the Mediterranean region to climate change and other forcing.[12] This multidisciplinary research line aimed at addressing vulnerability across the main sectors (e.g. agriculture, forestry, terrestrial ecosystems, water) and related ecosystems services providing a comprehensive picture of the state of vulnerability of the Mediterranean region (Hoff, 2013). The main findings point out how diversity in biophysical and socio-economic aspects characterizes the Mediterranean region, with great variations between the northern and the southern Mediterranean, and between the southern and eastern Mediterranean sub-regions. Given this context, there is large scientific consensus based on General Circulation Models (GCM) projections on how decreasing precipitation and increasing temperatures in the southern and eastern Mediterranean will exacerbate aridness, land degradation and desertification in this region (Hoff, 2013).

Above all, water availability and water quality degradation (e.g. from pollution, overexploitation or increasingly also from seawater intrusion) have become limiting factors for Mediterranean social and ecological systems (Hoff, 2013). In some Mediterranean countries, water scarcity in combination

[12] CIRCE Research Line: Impacts of Global Change on Ecosystems and the services they provide.

with expected climate change-related phenomena like the increase of temperature and the decrease of precipitation, will lead to reduced runoff and groundwater minimum recharge and consequently to poorer water quality and less water availability. In particular decrease in groundwater recharge due to drier climate conditions creates water quality degradation in coastal Mediterranean aquifers. SLR associated to climate change has a significant role in the salt-water intrusion process, due to change of atmospheric pressure, increase of temperature and oceans expansion. A number of studies showed that under climate change annual river flow is expected to decrease in Southern Europe and increase in Northern Europe; changes are also expected in the seasonality of river flows with considerable differences over the European region (Arnell 2004 ; Milly et al. 2005 ; Alcamo et al. 2007). Reductions of average annual runoff (up to 50%) will be challenging the whole Mediterranean socioeconomic system which is based largely on water demanding activities such as recreation, tourism, and food production.

Key observed impacts and bio-geographical vulnerabilities in coastal areas, with special reference to the Mediterranean basin:

- ***Losses of coastal habitats and ecosystems***
- ***Exacerbation of aridness, land degradation and desertification***
- ***Decrease in annual river flow and decrease in groundwater recharge***
- ***Higher water stress and water scarcity***
- ***Degradation of water quality in coastal aquifers***
- ***Aggravation of low-lying coasts submersion and quicker erosion of beaches from sea-level rise and storm-related floods***
- ***Possible local salinization***
- ***Changes in biodiversity due to northward shift of marine species and changes in the distribution of phytoplankton biomass.***

Climate impacts and vulnerabilities across key sectors in Mediterranean coastal zones

Potential socio-economic consequences of climate variability and change vary for the different key coastal sectors in the Mediterranean sub-regions. The main impacts and existing vulnerabilities of the sectors Food production, Transport Infrastructure, Tourism and Water Management in coastal areas that will be exacerbated by climate change are summarised below, as they emerge from the available scientific literature.

Food production in coastal areas

Coastal zones frequently offer the ideal growing conditions for a range of valuable crops (e.g. vegetables, olives, and grapes) besides the primary activities linked to fisheries and aquaculture, which are important for the food security and economy of coastal communities.

The agricultural sector has already been experiencing negative impacts in the Mediterranean area (Peltonen-Sainio et al., 2010; Olesen et al., 2011) which will eventually result in overall crop productivity reduction in large parts of the southern Mediterranean over the next decades (Iglesias et al., 2011; Olesen et al., 2011). It is important to highlight that, depending on crop type and specific latitude, there will be significant sub-regional differences in term of yield increase or decrease (Skuras and Psaltopoulos, 2012). PAP/RAC reports a decrease (in value terms) of 21% by 2080 for the whole Mediterranean agricultural production, with peaks of an almost 40% decrease in countries like Morocco and Algeria (UNEP/PAP/MAP, 2015).

Specifically, already observed changes in crop phenology such as advancement of flowering due to warmer temperature conditions are expected to continue in many Mediterranean countries, leading to overall reductions, for example, in grain production. Also, warmer temperatures will lead to increased risk of plants and livestock diseases as suitable climatic conditions for the invasion of (new) weeds, pests and other diseases arise.

Importantly, loss of arable lands caused by coastal erosion and salinization due to sea level rise and flooding could strongly limit agricultural production in coastal areas of the Mediterranean.

Regarding fisheries, the influence of climate change on this sector is the result of complex interactions between environmental factors, use of resources and economic drivers, which entail further interactions and synergies that have not been fully investigated yet (Daw et al., 2009).

IPCC reports that fisheries may be impacted either negatively or positively depending on the latitude, location, and climatic factors (Wong et al., 2014). It is commonly acknowledged that most of the fish stocks of commercial value are over-exploited making the fisheries sector in the Mediterranean Sea particularly vulnerable to further pressures. However, in many cases it can be difficult to distinguish between the effect of excessive fishing and the impacts of climate change.

The expected increase in the water temperature involves a latitudinal shift in the distribution areas of many species of commercial interest, as individuals tend to move, actively and/or passively, to the areas corresponding to their thermal optimum (Pörtner and Peck, 2010). This phenomenon has already been observed for many species of the Mediterranean (Ben Rais Lasram and Mouillot, 2009; Zenetos et al., 2012). In the eastern Mediterranean Sea, for example, the introduction of warm and tropical alien species from the Red Sea has greatly intensified over the last decades (Raitsos et al., 2010).

Another important aspect to be considered in future climate scenarios is the tendency to a reduction in the size of marine species in the Mediterranean. This was demonstrated for the fish fauna of the tropics, characterized by individuals who reach relatively small sizes compared to those of higher latitudes due to the different increase in the rate of consumption and intake of dissolved oxygen in relation to increasing size of the individuals (Pauly, 1998).

Acidification of the Mediterranean Sea waters (diminishing pH) due to the increase of atmospheric CO_2 concentration and consequently of the carbonic acid dissolved in the water, could have significant impact on animals and marine macro-algae with calcified body parts, because the calcification process could be slowed. Furthermore, increasingly frequent and longer summer heat waves could put large coastal areas at risk of hypoxia or anoxia phenomena. This would produce significant negative impacts on populations of less mobile species. Such impacts could involve negative consequences on fisheries for some important commercial species of gastropods, bivalves and crustaceans.

In summary, in addition to determining changes more or less marked in specific composition of the fishable resources locally, the warming of waters affects, through different mechanisms, different aspects of the physiology and phenology of the organisms, the dispersion and movement of nutrients needed for photosynthesis, the inter-specific relationships, trophic webs and, in essence, the functionality of the entire marine ecosystems.

Concurrently, for both agriculture and fisheries sectors, climate change will have a significant impact also on the safety and physical well-being of farmers and fishermen who will be exposed to increasingly frequent and more sever extreme weather events such as storms and heat waves.

Transport Infrastructure in coastal areas

IPCC states with high confidence that coastal industries, their supporting infrastructure including transport are highly sensitive to a range of extreme weather and climate events. Vulnerability to flooding of railroads, tunnels, ports, roads, and industrial facilities at low-lying areas will be exacerbated by rising sea levels or more frequent or intense storms, causing more frequent and more serious disruption of services and damages under extreme sea levels. However, the impacts on coastal industries and infrastructures vary considerably depending on geographical location, associated weather and climate, and specific composition of industries on the coastline (Wong et al., 2014).

In the Mediterranean, port and harbor infrastructure is expected to be at risk mainly due to the rise in sea level. Negative impacts are also expected from large waves generated by storm surges and floods/landslides especially in the Northern Adriatic (Lionello et al., 2012). These phenomena are likely to cause damage to infrastructure, interruptions and bottlenecks in the flow of products through ports. In general, port infrastructure will experience disruption of "just in time" delivery of goods, welfare losses, as well as increased cost for reparation and maintenance. Increasing wind speeds present challenges to the berthing of ships, and the operation of harbor equipment. Changes in water temperature and water quality can lead to invasive species causing damage to wooden structures, and the fouling of ships and harbor facilities.

As a result, marine navigation in the Mediterranean will be affected by such negative impacts on the port facilities caused by SLR, which do not offset the possible positive impact produced by the deepest depths that reduce the need for dredging in port areas (PIANC, 2008). Maritime transport could also experience limited navigability due to changes in sedimentation rates and location of shoals.

Road and rail transport networks located on the Mediterranean coastline can be negatively affected by SLR and sea storms causing increased risks of inundation and erosion, leading to disruptions in the transport of goods and in the mobility of local communities. Moreover, increased inspections and repairs may become necessary due to erosion of transport structures caused by inundation and saline intrusion.

Finally, the workforce of the transport sector will be increasingly exposed to hazardous extreme events.

Tourism in coastal areas

Available studies predict that summer tourism will be the most impacted by climate change on the coastal destinations of the Mediterranean (Amelung and Moreno, 2009). These impacts could result in an overall variation of the distribution of tourists, rather than the volume of tourism. It is likely that climate change will cause a shift in the choice of tourist destinations towards greater latitudes and altitudes, while tourists from more temperate climates are expected to spend more and more time in their countries of origin. However, the relationship between the impacts of climate change and specific tourist behaviour, activities, or flows to coastal destinations is still greatly uncertain (Moreno and Amelung, 2009).

The Mediterranean area will be adversely affected by this phenomenon, although to a lesser extent compared to tropical and equatorial regions (Hamilton, Maddison and Tol, 2005). Also, the tourism season could experience a shift from the hot summer months to the spring and autumn months, with an increase in the influx of tourists to the coast in the periods when the air and water temperature will be more pleasant. The findings of the CIRCE research line on coastal tourism in Southern Europe (Magnan et al., 2012) reveal that projected climate change may even generate beneficial impacts for tourism in northern Mediterranean countries, at least in the medium term, thanks to reduced precipitation and higher temperatures.

Specifically, the climate change-related impacts that are likely to affect coastal tourism concern first of all the aggravation of erosion, which entails the loss of land caused by rising sea levels and the intensification of storms, and the subsequent disappearance of coastal areas and infrastructure relevant to tourism activities, such as beaches and marinas.

Rising temperatures and, in particular, the increased frequency of heat waves in the summer are another main issue of concern for the tourism sector in the Mediterranean, causing discomfort and leading to a loss of attractiveness of coastal areas for tourists.

Finally, the rise in temperatures could lead to exacerbation of population explosions events in marine organisms, such as algae and jellyfish bloom, or mass mortality of corals and certain molluscs, which will entail adverse consequences in terms of biodiversity and in turn affect the attractiveness or accessibility of existing holiday locations in the Mediterranean Sea.

Water management in coastal areas

The impacts of climate change on water management cut across all major socio-economic sectors in the Mediterranean. The intense anthropization of coastal areas and coastal aquifers puts water supply under constant pressure. In this context climate induced drivers are likely to aggravate existing vulnerabilities and generate new risks.

For instance, aquifers are exposed simultaneously to the reduction of the natural recharge, an increase of withdrawals, and the input of pollutants from civil, industrial and/or agricultural sources. These factors result in a decline in the quality of water resources, particularly relevant in coastal aquifers, where the impact of saltwater intrusion has also to be taken into account.

Another important consequence of climate change on the water cycle is the reduction of the availability of water resources. Problems of growing competition for scarce water resources between alternative uses may arise for tourism, energy generation and agriculture resulting in higher costs for services (e.g. water supply, heat). Competition over water resources could also become a source of tension between nations in the case of transboundary river basins (EEA, 2012).

In particular, the increased vulnerability of the water sector to climate variability and change will reflect on the coastal agricultural activities. Regarding water quantity, the reduction of availability of water could cause an increase in competition between rural and urban water needs, worsening the existing conditions of water stress in rural areas. Also, progressive impoverishment of the quality of water resources is expected, with evident phenomena of salinization and pollution due to overexploitation. The impact of agricultural fertilizers will be greater under climate change: higher concentrations of nitrates in warmer receiving watercourses will lead to adverse impacts on water quality.

The reduction in rainfall and the occurrence of droughts, and the possible decrease in dam safety, and damage to infrastructure caused by flooding and landslides are believed to be the main responsible for the loss of productivity in the hydro-energy sector (Pirker, 2007). Overall estimates report that by 2070, the production potential of hydropower will decrease by approximately 6% on a European scale, but between 20% and 50% in the Mediterranean region.

The risk of desertification and decrease of water resources generates indirect impacts on the Mediterranean coastal tourism. Water availability tends to be scarce due both to the reduction in precipitation expected especially in the peak season (resulting in even greater risk of occurrence of fire), and the saline water intrusion in water supplies. This issue is particularly relevant given the already strong impact of tourism activities on water resources (Amelung and Moreno, 2009).

In terms of water quantity, southern and eastern Mediterranean countries are considered to be more vulnerable to climate change than northern countries because of projected aridness combined with greater climate variability and lower adaptive capacity (Hoff, 2013).

Table 1. Matrix of main socio-economic impacts and vulnerabilities in key coastal sectors due to expected physical and chemical impacts of climate change in the Mediterranean

Key Coastal Sectors ______________ Physical and chemical impacts of climate change	Food production	Transport Infrastructure	Tourism	Water management
Higher temperatures / heat waves	Evapo-transpiration and heat stress to crops Changes in crop phenology, leading to reductions in grain yield Conditions suitable for invasion of weeds, pests and diseases Increased risk of livestock diseases Mass mortality of marine populations of commercial interest (gastropods, crustaceans, molluscs)	Operational efficiency of assets and infrastructure Impact on health and safety of workforce Impacts on storage of goods Increased demands for cooling water	Decreased comfort and attractiveness Changes in tourist choices	Poorer water quality

	Impact on safety and physical well-being of workforce			
Higher sea water temperatures	Latitudinal shift of commercial fish species Reduction in fish size	Invasive fish species damaging wooden structures	Degradation of marine ecosystems (algae and jellyfish bloom) and decreased attractiveness	
Acidification of sea waters	Reduction of marine populations of commercial interest (gastropods, crustaceans, molluscs)			
Increased water stress and scarcity, Droughts	Increasing irrigation requirements Decreased suitability for rain-fed agriculture Droughts leading to further negative effects on agriculture (e.g. loss of crops and animal stock, loss of arable land, desertification)	Impact on operation efficiency of assets	Decreased comfort	Increased competition between rural and urban water needs and sectors (energy, agriculture, tourism) Increased tension between nations in case of transboundary waters
Poorer water quality	Further pollution	Discharges will have greater impacts on water quality	Health impacts	
SLR	Loss of arable lands due to salt water intrusion/coastal erosion leading to reduced production	Disruption of coastal roads and rails Disruption in transport of goods and mobility of communities	Impact on beaches	Increasing saline intrusion into coastal aquifers and ground water sources

		Devastation of port infrastructure, interruptions and bottlenecks in the flow of products through ports Increased maintenance of transport networks		
Storm surges / Extreme weather events	Increased flood risks to coastal agriculture Impact on safety and physical well-being of workforce Loss of arable lands due to coastal erosion/saltwater intrusion leading to reduced production	Disruption on coastal roads and rails, and port and harbor infrastructure Changes in sedimentation	Damage and eventual loss of coastal tourism assets and infrastructure due to flooding and erosion e.g. beaches, marinas	Increasing saline intrusion into coastal aquifers and ground water sources

Adaptation actions and ICZM in the Mediterranean coastal zones

Adaptation is commonly defined as a range of actions responding to current and future climate change impacts and vulnerabilities as well as to the current climate variability within the context of ongoing and expected societal changes (EEA, 2013).

However, it proves extremely complex to anticipate whether actions taken today will meet the challenges of tomorrow, especially when science cannot provide definite predictions on the intensity and frequency of future climate change impacts at the local and regional levels. Uncertainty is not expected to decrease over time, but rather to grow as new processes are investigated by climate science, and socio-economic drivers, such as demography, economics, and technological progress, keep interacting continuously among them and with the climate system generating new scenarios of change. Therefore, procrastinating action in the name of scientific certainty is not wise or desirable. On the contrary, adaptation strategies and measures should be inspired by the so-called "precautionary principle", which would ensure that uncertainty about the damage to be incurred does not serve as an argument to delay action within the limits of available knowledge.

In this respect, "maladaptation" has become one of the most used keywords within the adaptation community implying the risk of negative side effects caused by any adaptation or mitigation decision. In view to mainstreaming adaptation into development and sectoral policies, the fundamental approach should be for decision-makers to avoid actions that may lead to increased risk of adverse climate related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future (IPCC, 2014).[13]

[13] IPCC AR5 WGII contains a comprehensive section on "Addressing Maladaptation".

It is worth referring to existing guidelines to help make an informed assessment before any adaptation (and mitigation) decisions are made, adopting an ex-ante approach. For instance, an assessment framework developed by Magnan (2014) about maladaptation to climate change in coastal areas considers three main dimensions of maladaptation (environmental, socio-cultural and economic maladaptation) and ways to avoid it. It is based on the assumption that initiatives that address many or all of the guidelines will have a lower risk of maladaptation compared to initiatives that address few or none of them as presented in Figure 1.

Figure 1. Guidelines to avoid maladaptation in coastal areas (Source: adapted from Magnan, 2014)

Environmental maladaptation	Socio-cultural maladaptation	Economic maladaptation
•Avoid degradation that causes negative effects in situ •Avoid displacing pressures onto other environments (neighbouring areas or areas that are connected ecologically or socio-economically) •Support the protective role of ecosystems against current and future climate-related hazards •Integrate uncertainties concerning climate change impacts and the reaction of ecosystems •Set the primary purpose as being to promote adaptation to climate-related changes rather than reduce greenhouse gas emissions	•Integrate local social characteristics and cultural values about risk and the environmental dynamics •Integrate and develop local skills and knowledge related to climate-related hazards and the environment •Call on new skills that the community is capable of acquiring	•Promote the reduction of socio-economic inequalities •Support the relative diversification of economic and/or subsistence activities •Integrate any potential changes in economic and subsistence activities resulting from climate change

With respect to the various typologies of adaptation responses, the policy community categorises actions according to their characteristics as soft, green and grey adaptation. These can be implemented as stand-alone measures or be combined to tackle more than one solution (EC, 2009; EC, 2013):

- **Soft actions:** informational, governance and capacity building measures involving managerial, legal and policy solutions that alter human behaviour and styles of governance.
- **Green actions:** operational measures with ecosystem-based approaches that use the multiple services of nature.
- **Grey actions:** operational measures such as technological and engineering solutions.

A variety of soft, green and grey adaptation measures are available for coastal areas. These range from building protection against flooding (e.g. construction of dikes, groynes, breakwaters and artificial reefs; beach and shoreface nourishment; restoring coastal ecosystems), accommodating and improving existing conditions of assets and population (e.g. adaptation of flood management plans; cliff stabilization; flood-proofing of buildings and critical infrastructure), to addressing behavioural change and risk awareness (e.g. awareness campaigns; adapting behaviour in flood prone areas; financial tools for risk management; retreat from the coastline) (Klein et al., 2001; Wong et al., 2014).

Against the substantial vulnerability of coastal areas to the impacts of climate change in the next century, coastal authorities are especially encouraged to undertake adaptation initiatives and measures that are integrated into national ICZM strategies. In this view, a Regional Climate Change Adaptation Framework being developed under the auspices of UNEP/MAP aims at providing a regional approach in coordinating and assisting stakeholders and policy makers at all levels across the Mediterranean to take action in order to increase the resilience of the coastal natural and socio-economic systems to the impacts of climate change.

In the frame of the MedPartnership Project, PAP/RAC produced **guidelines for the preparation of national ICZM strategies required by the ICZM Protocol for the Mediterranean** (UNEP/MAP/PAP, 2015a) based on worldwide best practices and the current state-of-the-art in ICZM and related fields.

These guidelines revolve around a list of key features that the National ICZM Strategies for the Mediterranean should comprise, as follows:

- Inclusive stakeholder involvement in their preparation and implementation;
- Approval at highest political level and high-level inter-ministerial co-ordination;
- Focus on harmonisation and alignment with other relevant plans and policies, including climate change, and an effective regulatory framework;
- Include strategies for communication, financing and capacity building for ICZM;
- Focus on implementation, delivering tangible results on the ground;
- Include the coastal zone in its entirety including territorial waters, integrating both land and sea;
- A platform for the preparation and implementation of coastal plans and programmes, for transboundary and for international co-operation;
- A key national tool towards achieving objectives of the Mediterranean Strategy for Sustainable Development and the overall implementation of the Barcelona Convention.

In addition to that, in the context of the ClimVar & ICZM Project, PAP/RAC developed **guidelines for coastal planners on how the impacts of climate variability and change can be integrated into the ICZM process**, including lessons learned from the experience of handling climate variability and change in specific locations in the Mediterranean region and elsewhere (UNEP/MAP/PAP, 2015b). The report provides comprehensive guidance on the five stages of planning an ICZM strategy, plan or programme as illustrated in Figure 2 below.

Figure 2. Five stages of ICZM planning integrating adaptation (Source: adapted from UNEP/MAP/PAP, 2015b)

Establishment, which sets out the ICZM strategy and plans within the context of the ICZM Protocol

Analysis and Futures, which involves building the scientific evidence and identifying future projections

Setting the Vision, which implies engaging stakeholders in setting priorities and agreeing on key policies and measures for the analysis stage

Designing the Future, which involves identifying the best vulnerability assessment approaches and proofing methodologies, formulating plans to deal with climate impact and establishing a management structure

Realising the Vision, which covers the implementation of the strategy

It is widely acknowledged among scientists and practitioners that the identification of adaptation actions must be made *ad hoc* based on the assessment of local conditions of impacts and risk/vulnerability and the analysis of costs and benefits of options to adapt. Consolidated inventories of possible adaptation measures can offer inspiration when planning for adaptation, although this is no substitute for developing *ad hoc* responses.

At the European level, **Climate-ADAPT[14] represents the main "Climate Adaptation Portal"** providing information and data on adaptation and tools specifically designed to facilitate policy makers to understand and implement adaptation. It was called for by the European Commission in the White Paper on Adaptation to Climate Change (EC, 2009) and was launched in 2012 being currently maintained by the European Environment Agency. Climate-ADAPT allows to explore potential adaptation options by selecting a specific climate

[14] Climate-ADAPT: http://climate-adapt.eea.europa.eu/adaptation-measures

impact, including sea level rise and flooding, and / or adaptation sector of interest, including coastal areas. Case studies of adaptation measures implemented in specific regions can also be investigated for comparison with similar bio-geographical areas. Climate-ADAPT has a wider European scope also covering information and data related to neighbouring countries that stem from EU projects and initiatives such as the Mediterranean Programme[15] for transnational cooperation, the European Neighbourhood Policy (ENP)[16] for the South Mediterranean and the Euro-Mediterranean Partnership (EUROMED)[17].

For European coastal zones, the **EU-funded project OURCOAST[18] maintains the "European portal of ICZM"** with the aim of sharing good practices of integrated coastal management in a context of climate change adaptation and supporting the decision-making process towards a more integrated and sustainable approach. The database can be searched with a geographical filter allowing to discover good practice examples in the Mediterranean Sea region. For every good practice case a factsheet provides useful links and detailed information on the measures implemented, including costs, success and fail factors, as well as unforeseen outcomes. The OURCOAST database has the advantage to offer a wide selection that can inspire policy makers of other Mediterranean countries with good practice examples of the three types of adaptation measures implemented through ICZM tools.

For the purpose of providing relevant examples of adaptation that are viable in Mediterranean coastal zones and coherent with ICZM guidelines, we report a series of case studies taken from the OURCOAST database, contained in **Annex 1.**

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[15] Mediterranean Programme: http://www.programmemed.eu

[16] ENP: http://www.enpi-info.eu/indexmed.php?lang_id=450

[17] EUROMED: http://www.eeas.europa.eu/euromed/index_en.htm

[18] OURCOAST - Sharing of Best Practices on Integrated Coastal Zone Management (ICZM) in a Context of Adaptation to Climate Change in Coastal Areas: http://ec.europa.eu/ourcoast/index.cfm?menuID=3.

For the Mediterranean coastal areas specifically, **the Mediterranean Integrated Climate Information Platform (MedICIP)** [19] was developed within the frame of ClimVar & ICZM Project with the aim to share data information on climate change. The technical design was carried out by the University of Geneva and UNEP/GRID Geneva under the assistance of Plan Bleu and UNEP/MAP. MedICIP is intended as a "portal of portals" which gathers data, information and web links towards other institutions (national and regional). MedICIP is based entirely on reliable open-source software, so to build an efficient, scalable and customizable platform, with interoperable local Spatial Data Infrastructures (SDIs) in the countries.

MedICIP allows participating countries to exchange knowledge, information, data and metadata on climate variability and change, impacts, vulnerability an adaptation measures; support the implementation of ICZM protocol by giving access to a maximum of relevant data sets and information (such as that on management methods for climate risk and adaptation); serve as support to integrated climate risk and opportunity management in a number of socio-economic sectors; respond to the objectives of the Global Framework for Climate Services (GFCS); make use of expertise available in at the national level.

MedICIP has the following functionalities: a Spatial Data Infrastructure (SDI) able to hold a local metadata catalog, to harvest external metadata catalogs and to serve data and metadata through interoperable and standardized web services; an online Mapping interface allowing users to display, search for, integrate geospatial data, and export data sets and maps; a reference information database allowing users to search for reference information/institution/stakeholders/experts/existing monitoring programs/reports on climate impacts and adaptation, by: keywords, countries, thematic.

[19] MedICIP: http://medicip.grid.unep.ch

Sub-regional pilot studies

As a contribution to the key objectives of the ClimVar and ICZM Project, PAP/RAC presented a novel quantitative countrywide assessment of the sea-level rise related climate impacts based on the DIVA (Dynamic and Interactive Vulnerability Assessment)[20] model and database, which was downscaled to adequately address data and information at the national level for two demonstration sites: Croatia and Tunisia. The studies investigate the potential impacts causing increased risk of coastal flooding and dry land loss and resulting damages, in case no adaptation action is taken to prevent or moderate these impacts. Furthermore, they assess the potential and cost of reducing coastal flood damage and impacts through grey infrastructural adaptation (dikes as protection against the current extreme water level regime). At the time of this research, only the outcomes of the Croatian case study were available to be shared.

The demonstration study conducted in the Šibenik-Knin County of Croatia (Pohv Škugor and Sekovski, 2015), provides an overview of the economy as well as climate change trends and projections in the sub-region, systematically analyses the impacts of climate change on tourism, agriculture, fisheries and aquaculture, water management and other relevant sectors such as manufacturing, maritime transport and energy, and presents the results of the application of the DIVA model highlighting the impacts of sea level rise, sea floods and other climate impacts on the Croatian coastline (see Hinkel et al 2014; Baučić, 2014). According to the DIVA projections, the area of coastline flooded due to a 1-in-a-100-year flood is expected to dramatically increase over the next decades, from less than 50 km^2 now to 280-340 km^2 in 2050 and to 320-390 km^2 in 2100. Consequently, the value of assets potentially affected by such event rises from less than $10 billion

[20] 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. DIVA model: www.diva-model.net

at present to $40-70 billion in 2050 and $76-154 billion in 2100. However, the impacts are expected to be less severe on the population, with a total of 101,000 people at risk now, 102,000 to 117,000 projected in 2050, and in 74,000 to 125,000 in 2100. In summary, the results of DIVA study in Croatia indicate that although the impact on the population is limited, the costs of sea floods are considerable (18.75% of the total sea flood costs for the entire country). Greatest potential impacts will manifest themselves in damage to coastal assets. This implies increased risks for settlements and tourism facilities located in the low-lying coastal zones, as well as nautical tourism assets and UNESCO World Heritage Sites. With this method, it is possible to estimate the costs of a sea-flood for all of Croatia, assuming no further action is taken in terms of adaptation. Whereas in 2010 the expected annual flood costs were around $0.26 billion, under the high sea-level rise scenario the annual damages by sea-floods could range from $4.4 to $5.8 billion in 2050, and $39 to $58 billion in 2100. Under the low sea-level rise scenario the expected damages are much lower, ranging from $1.6 to $2.1 billion in 2050 and from $6.0 billion to $9.0 billion in 2100.

The report provides a series of policy considerations and sectoral prospects to build the resilience of the Šibenik-Knin County, starting from constructing adequate protection for those locations with high-value assets, and integrating future climate projections into development strategies and land-use plans.

Regional Risk Assessment: Implementation of the Multi-scale Coastal Risk Index in the Mediterranean (CRI-MED)

In this section

Section 2 provides an overview of existing tools and methods to evaluate climate risk and vulnerability that was functional to the selection of an appropriate methodology for this study. Furthermore, a detailed methodological framework presents the necessary assumptions and adjustments that were considered for the purpose of this study. Finally, the section includes the outcomes of the implementation of the proposed methodology for the regional risk and vulnerability assessment carried out in the coastal zones of the eleven Mediterranean countries involved in the ClimVar & ICZM Project. The analysis is followed by the discussion of results and limitations of the methodology used.

Overview of existing tools and methodologies to evaluate climate vulnerability and risk

As part of the early scoping phase for this study, an analysis has been undertaken to evaluate existing methodologies and tools to assess vulnerability and risk to the impacts of climate variability and change at regional, sub-regional and local level. The purpose of this evaluation is to provide a foundation for the development of a new family of tools for vulnerability and risk assessment both for the regional and local scale in the Mediterranean as core objective of this project.

The methodology of this evaluation is presented below, followed by the outcomes of the analysis.

Methodology for the evaluation

As previously stated, the purpose of this evaluation is to inform the process of development of a methodology for evaluating regional, sub-regional and local vulnerability and risk in the Mediterranean, which in turn should meet Mediterranean data requirements, build on existing Mediterranean decision-making processes and satisfy Mediterranean stakeholders. To this end, this analysis of tools focuses on those originating in and designed for the Mediterranean region as well as those assessing risks and vulnerabilities relevant to the Mediterranean region. Tools designed for a much broader range of places and sectors are also included in order to draw on best practice risk and vulnerability assessment processes from around the world.

Tools were included that address some component of decision-making on climate variability or change, either at a theoretical, practical or integrated level. **These cover four main categories:**

Methods based on dynamic computer models. These methods aim to model current and potential future conditions of geophysical, biological, and/or socioeconomic processes. The complexity of the models generally requires appropriate hardware and software, advanced scientific expertise and "it is important to consider data requirements when assessing their appropriateness" (Rozum & Carr, 2013).

Visualization tools. These tools are imagined to simulate current, and potential future conditions of climate change impacts. They represent an easier GIS based application then GIS Based Decision Support System (DSS). Visualization tools "are generally easy to use and do not require specialized software or hardware" (Rozum & Carr, 2013).

Index/Indicators based methods. Index methods are based on the quantitative or semi-quantitative evaluation and combination of several variables. Indicator-based approaches, express the vulnerability of the coast by a set of indicators that characterize key coastal issues such as coastal drivers, pressures, state, impacts, responses, exposure, sensitivity, risk and damage (ETC-CCA, 2011). The methods that use indicators are based on a set of broad or less broad indicators. Aggregation in a single value is characteristic of the index-based approaches. These methods have in common that the result is a combination of a summary of a specific index or indicators. In general, this summary is expressed by a formula which aggregates indexes and indicators according to an appropriate set of weights.

GIS-Based Decision Support Tools. These tools aim to build scenarios resulting from potential climate change impacts to support coastal decision-makers and practitioners to take the best management decisions investigate a wide variety of assessment outcomes (Rozum & Carr, 2013). These tools require specific GIS expertise and advanced technical capacities.

Tools were identified through the use of expert knowledge, requests to relevant organisations, targeted internet searches and supplemented by comparisons with relevant literature reviews.

In order to evaluate the tools appropriately, evaluation criteria were selected that reflect the needs of the new methodology framework to be developed. **Each tool was assessed by applying an expert judgment against the following criteria:**

- **Format, accessibility and ease of use.** The method tool is available (online) in common digital formats, easy to use while providing flexibility sufficient enough to adjust to local conditions. In particular, the use of the tool must be intuitive and accessible for practitioners more than for scientists. As a plus, outputs are easy to integrated into the planning process, such as maps, indices and indicators, or charts. The costs for the purchase and the implementation of the method must be affordable for the budget of a local coastal community.

- **Relevance to the Mediterranean coastal areas.** The method/tool was specifically designed for the use in the Mediterranean region and/or previously applied or potentially applicable to assess climate change in Mediterranean coastal areas. In particular, it is applicable to different coastal profiles and to different coastal ecosystems.
- **Based on ICZM approach.** The method/tool incorporates ICZM guidance by addressing land and sea components simultaneously and taking into account the interdependence of natural systems and human activities with an impact on coastal areas.
- **Relevance for building adaptation options.** The method/tool has the capacity to identify the best adaptation measures. Vulnerability and risk assessment methods work best when they are focused on the preliminary questions that the adaptation planning processes must address.
- **Economic/costing information.** The method/tool allows to estimate the economic impacts of climate change for the area or sector of application.
- **Multi-scale approach.** The method/tool is suitable for its application at regional, national and local scale. To be relevant to the local the tool must reach the minimum level of 1 - 10 km2 in terms of coastal area.

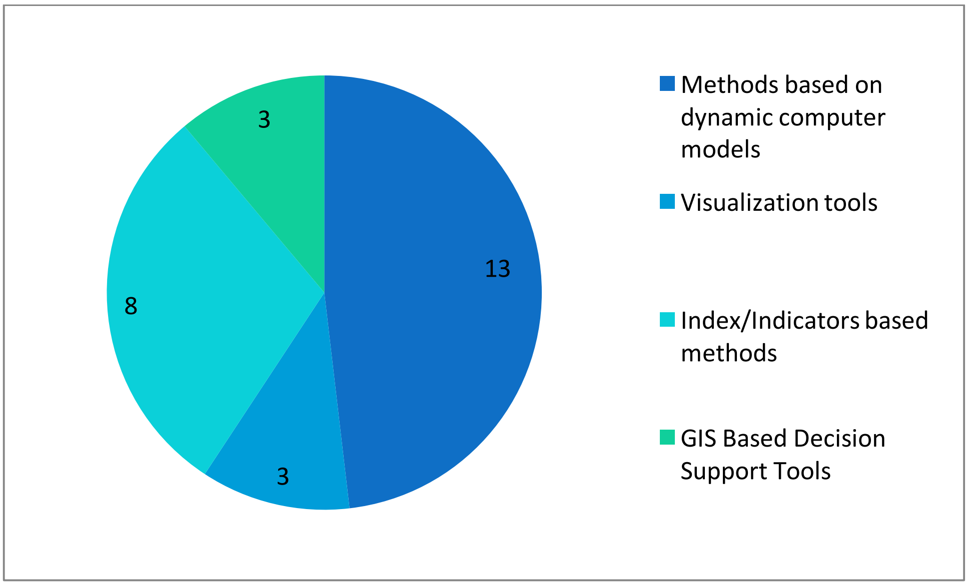
The compliance of the identified methods with the 6 proposed selecting criteria is evaluated using a simple scoring system based on 3 levels (1 = low compliance, 2 = medium compliance, 3 = high compliance).

Results

Twenty-seven (27) vulnerability and risk assessment tools were selected in total, which are all documented in **Annex 2.** For each of these tools information on the developer, category, short description and main objectives is provided. It has to be acknowledged that the analysis contained in Annex 2 represents a simplification that cannot always grasp the articulation and complexity of the methods developed, but it is also necessary for a prompt comparative analysis.

Among the methods and tools selected the most popular category was "Methods based on dynamic computer models" (13), followed by the category "Index/Indicator based methods" (8), with only few examples of "Visualization Tools" (3) and "GIS Based DST" (3).

Figure 3. Analysis of selected methods and tools per category (source: own elaboration)



According to our review, seven (7) methods out of 27 are considered particularly satisfactory of our criteria and especially relevant for the application to the Mediterranean scale in this study, having reached a score of 14 or above.

These are: CCFVI (Balica et al., 2010); CVI-SLR (Özyurt, 2007), DESYCO (Torresan et al., 2010), DIVA (Hinkel, 2005), Multi-scale CVI (McLaughlin & Cooper, 2010), RVA - Regional Vulnerability Assessment (Torresan et al., 2012), SimCLIM (CLIMsystems Ltd). This further selection is shown in more detail in Table 2.

All these selected methods are considered to be particularly relevant to decision maker to build a set of adaptation options. While the identified index-based methods (CCFVI, CVI-SLR, Multi-scale CVI, RVA) and GIS-based methods (DESYCO) have a relatively easy calculation process, in general methods based on dynamic computer models require a certain degree of expert knowledge to make effective use (especially DIVA). Regarding the possibility to obtain data and information on the costs of climate change, the best tools within our further selection are considered to be DIVA and SimCLIM followed by RVA and DESYCO.

Several methods identified, like CVI-SLR, DESYCO and DIVA have already been successfully applied in the Mediterranean context and others show clear adaptability to the Mediterranean and local scale, like SimCLIM and, in general, the index-based methods. In particular the Multi-scale CVI method by McLaughlin and Cooper has a considerable potential to be employed at the local scale (like other models, the data used to produce the indicators varies according to the scale of application).

In this respect, the Multi-scale CVI method by McLaughlin and Cooper emerges from our selection as it is fully compliant with all the selecting criteria, except for the possibility to obtain some form of economic appraisal of climate change.

For the regional and local assessment to be implement in this study, the Multi-scale CVI was deemed to be the method that best fits for purpose, as, besides the characterization of physical elements, it also integrates a large set of socio-economic variables. Furthermore, in the Multi-scale CVI the vulnerability assessment targets are represented by variables that are separated into three sub-indices. As such, the model is not expensive and has an easy calculation process to analyse the different vulnerability factors. It can easily integrate the concept of risk as proposed by IPCC AR5. It is applicable at the regional and local scale and the outcomes consist of vulnerability maps at the most adequate level of downscaling.

For these reasons, the Multi-scale CVI was selected as the reference methodology whose features and advantages are fully described in the next sections.

Strengths of the Multi-scale CVI method:

- ***Integrates physical as well as socio- economic variables***
- ***Three separated sub-indices representing vulnerability***
- ***Not expensive and easy calculation process***
- ***Easily integrates the concept of risk***
- ***Produces vulnerability maps***
- ***Applicable both at regional and local scale.***

Table 2. Database of relevant method and tools for climate risk and vulnerability assessment (source: own elaboration)

Scoring system: 1 = low compliance, 2 = medium compliance, 3 = high compliance

Method	Developer	Category	Description	Objectives	Format, accessibility, ease of use	Relevance to Med coastal areas	Based on ICZM approach	Relevance for building adaptation options	Economic/costing info	Multi scale approach	Tot score
CCFVI	Balica et al., 2010	Index/Indicators based methods	The CCFVI system can be used as an instrument to assess which areas are most vulnerable to flood. This system helps decision-makers to control the possible damages and distinguish the precise measures for implementing before flooding (Balica and Wright, 2010). The Flood Vulnerability Index can be used in action plans to manage flooding and can improve local decision-making practices with appropriate measures to reduce vulnerability in different spatial levels (Balica et al., 2009).	To calculate flood vulnerability in certain areas.	3	2	3	3	1	2	**14**
CVI (SLR)	Özyurt, 2007	Index/Indicators based methods	It defines 5 CVI sub-indices, each one related to a specific sea- level rise impact. These are integrated in a final CVI (SRL) index. It can be integrated to GIS to produce maps. The input parameters are: 12	To assess vulnerability of physical system, socio-economic (i.e. land use) and	3	3	2	3	1	2	**14**

			physical (e.g. geomorphology, sediment budget and water depth at downstream) and 7 human influence (e.g. reduction of sediment supply and land use pattern) parameters.	ecological systems							
DESYCO	Torresan et al., 2010	GIS Based Decision Support Tools	The model provides vulnerability maps by GIS, Hazard maps, Exposure maps, Susceptibility maps, Value maps, Vulnerability maps, Risk maps, Damage maps.	To assess socio-economic and ecological vulnerability	3	3	3	3	2	1	**15**
DIVA	Hinkel J., 2005	Methods based on dynamic computer models	Estimates of population flooded wetland changes, damage and adaptation costs, amount of land lost. The model requires elevation (SRTM), geomorphic and form types, coastal population, land-use, administrative boundaries, GDP	To conduct national assessment of vulnerability in small island nation; Socio-economic and ecological targets	1	3	3	3	3	1	**14**
Multi-Scale - CVI	McLaughlin & Cooper, 2010	Index/Indicators based methods	It defines 3 sub-indices: coastal characteristic sub-index, coastal forcing sub-index, and socio-economic sub-index. Final CVI index. Indices can be represented in maps. Key variables are defined according to the specific application (location and scale). Variables refer to: resilience and coastal susceptibility to erosion, forcing variables contributing to wave-induced erosion socio-economic target potentially at risk	To produce indexes (and maps) representing socio-economic and ecological vulnerabilities	3	3	3	3	1	3	**16**

RVA - Regional Vulnerability Assessment	Torresan et al., 2012	Index/Indicators based methods	Based on a system of numerical weights and scores, the RVA provides relative vulnerability maps that allow to prioritize more vulnerable areas and targets of different climate-related impacts in the examined region and to support the identification of suitable areas for human settlements, infrastructures and economic activities, providing a basis for coastal zoning and land use planning. The has been applied to the coastal area of the North Adriatic Sea (Italy).	To identify key vulnerable receptors (i.e. natural and human ecosystems) in the considered region and localize vulnerable hot spot areas, which could be considered as homogeneous geographic sites for the definition of adaptation strategies.	3	3	3	3	2	1	**15**
SimCLIM	CLIMsystems Ltd	Methods based on dynamic computer models	This model creates maps of areas/habitats potentially vulnerable to inundation. Spatial and site-specific scenarios of climate and sea-level changes; time-series projections, graphical and tabular output. It needs DEM, Elevation, site specific time-series data, patterns of climate and sea-level changes from GCMs, impact models.	To assess climate change impacts and adaptation (both socio-economic and ecological targets)	2	2	3	3	3	1	**14**

Introduction to the Multi-scale Coastal Risk Index for the Mediterranean (CRI-MED)

An Index-based method is one of the most commonly used and straightforward methods to assess coastal vulnerability and risk to climate driven impacts. The Index provides a simple numerical basis for ranking sections of coastline in terms of their potential for change that can be used by managers to identify regions where risks may be relatively high. The Index results can be displayed on maps (e.g. risk maps) to highlight regions where the climate drivers that contribute to coastal changes may have the greatest potential to contribute to these changes. According to IPCC (2014) definition, Risk is characterised as "The potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur".

Risk generated from particular coastal hazards can be considered at various scales. Since adaptation and ICZM are undertaken by organizations operating at various spatial scales, indices must address coastal risk at an appropriate scale (McLaughlin and Cooper, 2010).

At each scale of management there are different considerations and different types of data. There is no 'one size fits all' index of coastal risk that can be applied at all scales. The components that contribute to the index calculation, the data availability and type, and the utility of an index approach vary with scale. **The present study proposes a Multi Scale Coastal Risk Index (MS-CRI), based on a common methodological and theoretical framework, with one application at a regional level and a local level.**

The regional-scale application of the MS-CRI should enable international organization, such as UNEP/MAP, to define a broad picture of the coastal risk at the Mediterranean level and also to compare different levels of risk among Mediterranean countries. The risk assessment at national-scale level is addressed to countries for their prioritization of national adaptation strategies and programmes. The practical response to coastal hazards is, however, most commonly implemented at the local level (McLaughlin and Cooper, 2010).

In the following sub-sections, we present the application of the Multi-scale Coastal Risk Index to the regional scale in the Mediterranean, which we call CRI-MED.

The CRI-MED index developed in this work is a spatial risk index, which combines multiple data layers (or variables) representing different aspects of risk in such a way that coastal "hot-spots" as well as areas of relatively lower risk emerge from the integration of the layers.

> ***CRI-MED is a spatial risk index combining multiple data layers representing different aspects of risk that allows to recognize coastal "hot-spots".***

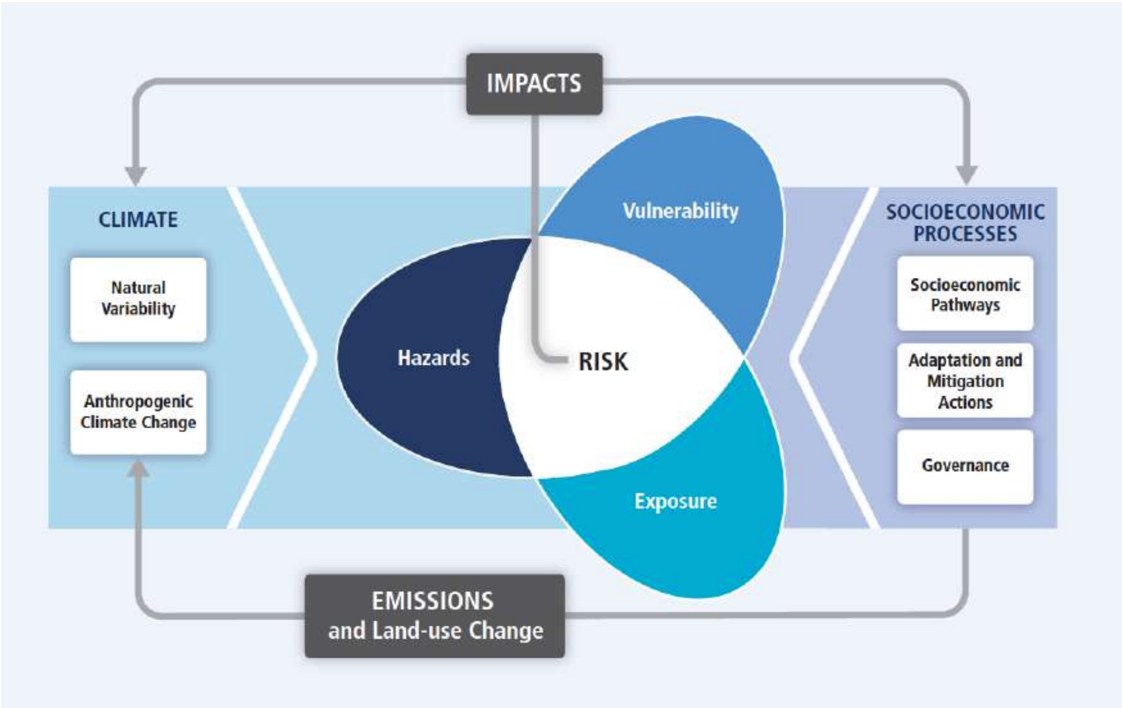
Literature review

The theoretical framework for Vulnerability and Risk in IPCC AR5

The contribution of Working Group II to the IPCC's Fifth Assessment Report (WGII AR5) focuses on "how impacts and risks related to climate change can be reduced and managed through adaptation and mitigation" (IPCC, 2014).

The most innovative elements of WGII AR5 include the focus on risk to support decision making in the context of climate change, and the concept of vulnerability as a factor contributing to risk as indicated in Figure 4.

Figure 4. Illustration of the core concepts related to Risk in AR5 WGII (IPCC, 2014)



Risk is defined as the results of the interaction of hazards with vulnerability and exposure of human and natural systems (IPCC, 2014). The Risk function proposed for this work introduces the forcing factor as the interaction between the climate and non-climate drivers and hazards (Satta, 2014):

$$\text{Forcing} = \text{Drivers X Hazards}$$

The resulting function is Risk = f (forcing, vulnerability, exposure). The Risk equation is derived though a multiplicative formula of the three factors (Satta, 2014):

RISK = FORCING x VULNERABILITY x EXPOSURE.

The Multi-scale Vulnerability Index by McLaughlin and Cooper

For the purposes of this work we refer to the **Multi-scale Vulnerability Index proposed by McLaughlin and Cooper (2010)** identified in the preliminary phase of this study. This index-based method was then appropriately amended to be compliant with the Risk conceptual framework defined by IPCC's AR5.

The McLaughlin and Cooper index integrates three sub-indices:

- A coastal characteristic sub-index, describing the resilience (e.g. age of population) and coastal susceptibility (e.g. landform, elevation);
- A coastal forcing sub-index, characterizing the forcing variables (e.g. SLR, Storms, Heavy Rainfall);
- A socio-economic sub-index, describing coastal targets potentially at risk, the exposure (e.g. land cover, total population).

The computation of each sub-index is determined on the basis of various variables, whose specific identification (number and typology) depends on the considered application scale. The identified variables (a set for each spatial scale analysed) are then ranked according to a 1-5 scale in order to express their contribution to the coastal system vulnerability; with 5 being the highest value and 1 the lowest. The 1-5 scale allows the mathematical combination of different variables. Sub-indices are calculated by the sum of the values of the relative variables; the obtained number is then standardised to the range 0-100.

The sub-indexes are calculated through the following formulas:

Coastal Characterization (CC) sub-index = $\{[(\text{sum of CC var.}) - n_{CC}]/ n_{CC} \times 4\} \times 100$

Coastal Forcing (CF) sub-index = $\{[(\text{sum of CF var.}) - n_{CF}]/ n_{CF} \times 4\} \cdot \times 100$

Socio-Economic (SE) sub-index = $\{[(\text{sum of SE var.}) - n_{SE}]/ n_{SE} \times 4\} \cdot \times 100$

Where: n_{CC} = number of CC variables; n_{CF} = number of CF variables; n_{SE} = number of SE variables.

The final CVI index is computed through the average of the three sub-indexes values, as shown in the formula below:

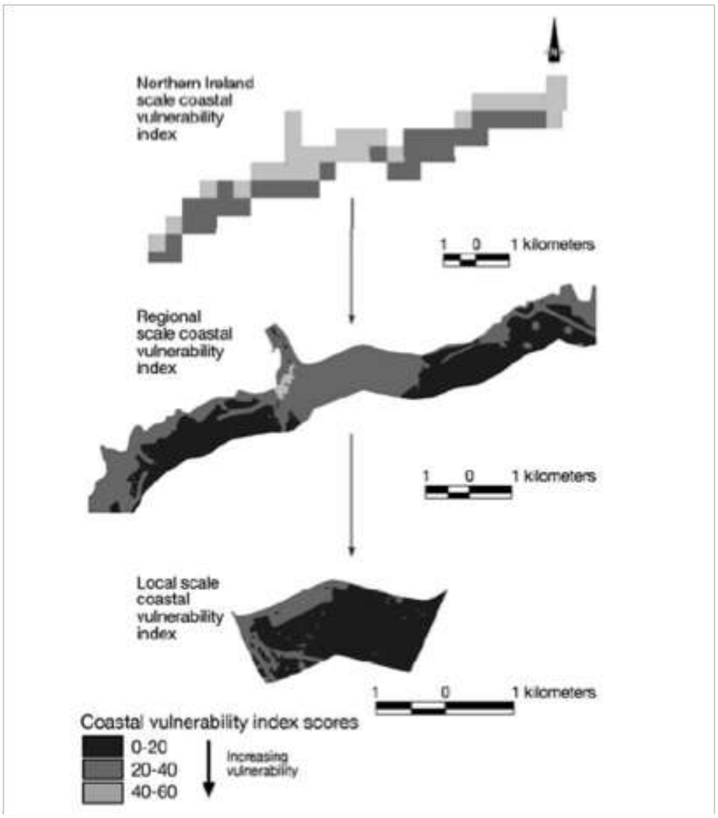
CVI = (CC sub-index + CF sub-index + SE sub-index) / 3

Importantly, CVI values can be visualized as a colour-coded vulnerability map.

The ranking of variables is a somewhat subjective exercise, and the criteria by which they are ranked must be clearly defined. Weighting different variables in relation to each other because weighting can be challenging due to the diverse number of value judgments that lie behind combined weights.

Although exact boundaries for coastal zones can be placed on administrative areas on maps, natural divisions in the coastal environment do not necessarily match with administrative boundaries. Availability of data is an important factor in the selection of parameters to depict vulnerability at each scale. The time taken to process data is also a consideration when data have to be extracted from larger datasets or secondary data are to be derived. At the local level, it is possible to identify infrastructure in potentially highly vulnerable areas; it could also be used to devise a local-scale development or coastal management and adaptation plans for the area. The results of the analysis will be reported in the form of colour-coded vulnerability maps, enabling to identify the most vulnerable areas and related adaptation options. At the local scale, assessment of adaptation options requires detailed analysis to capture the potential variation in the responses within a coastal zone for a certain time frame, rather than assuming a homogeneous adaptation response. ICZM is recognized as the most appropriate process to deal with climate change, sea-level rise and other current and long-term coastal challenges. An example of coastal vulnerability maps for Northern Ireland at different scales is presented in Figure 5 from McLaughlin and Cooper.

Figure 5. Vulnerability maps at different scales (source: McLaughlin and Cooper, 2010)



Methodological framework for the CRI-MED

Methodological assumptions

Based on the Multi-scale Coastal Vulnerability Index (McLaughlin and Cooper, 2010) and on the research developed by Satta (2014) we reworked the CVI Index to develop a Coastal Risk Index. We called CRI-MED the Coastal Risk Index applied to assess risk related to climate variability and change at the regional scale in the Mediterranean area.

We made the hypothesis that three factors contributing to risk should be multiplying each other (Satta, 2014). This is introduced because if the forcing is null, then the risk is null.

The risk could be also null if there are no assets in a coastal zone exposed to hazard (exposure = 0), same situation if the "coastal system" is not vulnerable, (vulnerability = 0, induce a risk = 0);

$$\text{Risk} = \text{Vulnerability} \times \text{Forcing} \times \text{Exposure}$$

According to WGII AR5 (IPCC, 2014), Vulnerability is "the propensity or predisposition to be adversely affected" and includes the concepts of susceptibility and lack of capacity to cope (or lack of resilience).

Referring to Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report (IPCC, 2014), vulnerability can be expressed as a function of Susceptibility and Resilience, where:

Susceptibility: Physical predisposition of human beings, infrastructure, and the environment to be affected by a dangerous phenomenon due to lack of resistance and predisposition of society and ecosystems to suffer harm as a consequence of intrinsic and context conditions making it plausible that such systems once impacted will collapse or experience major harm and damage due to the influence of a hazard event.

Resilience: The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

In this sense, AR5 considers Resilience as an internal component of Vulnerability.

We can express the Vulnerability function at least in two ways, as follows:

$$\text{Vulnerability} = \text{Susceptibility} - \text{Resilience}$$

and

$$\text{Vulnerability} = \text{Susceptibility} / \text{Resilience}$$

In the CRI-MED function we adopted the first equation and we defined the Resilience variables (Education Level and Pop Over 65). We inverted the scale of the scores of these variables to have just positive numbers.

The Vulnerability sub-index is formed by Susceptibility and Resilience variables.

Integrating these concepts in the Multi-scale Index we have three sub-indexes respectively representing Coastal Forcing, Coastal Vulnerability and Coastal Exposure:

$$\text{Coastal Forcing (CF) sub-index} = \{[(\text{sum of CF var.}) - n_{CF}] / n_{CF} \times 4\}$$

$$\text{Coastal Vulnerability (CV) sub-index} = \{[(\text{sum of CV var.}) - n_{CC}] / n_{CC} \times 4\}$$

$$\text{Coastal Exposure (CE) sub-index} = \{[(\text{sum of CE var.}) - n_{CE}] / n_{CE} \times 4\}$$

Where: n_{CF} = number of CF variables; n_{CV} = number of CV variables; n_{CE} = number of CE variables.

Adopting a multiplying formula the final Coastal Risk Index can be written as follows:

$$CRI = CF \times CV \times CE.$$

We assume that CE is always > 0. In fact, we consider that every category of Land Use has a value (e.g. in terms of loss of coastal land) and it can never be considered = 0. This hypothesis is even more valid when considering the uncertainties related to the construction of the Land Cover (e.g. LC CCI). Comparing the areas which have been rated as "bare areas" (which corresponds mainly to the desert areas) in the LC CCI with the same areas of GOOGLE EARTH, you realize that in some cases these areas correspond to the beaches with important dune systems, which obviously you can not assign a value of zero. We consider that risk is null only if Vulnerability or Forcing are null. We also assume that final score of CRI-MED is a number ranging between 0 and 1.

The CRI-MED method is based on the following steps:

- ***Definition of coastal unit for the regional analysis***
- ***Definition of the variables associated to each sub-index and scoring of variables classes (and eventually weighting)***
- ***Calculation of the three sub-indices and of the final index***
- ***Building the risk maps.***

Definition of the coastal unit

The geographical coverage of the present study corresponds to the field of application of the ICZM Protocol as defined by its Article 3. The limitation of "coastal zone" is a national matter and it has been largely discussed at the Mediterranean level with the aim to identify a common unit for regional studies and analyses. Currently there is no shared agreement for a coastal unit to be used for regional analyses. **Nevertheless, the application of the Coastal Vulnerability Index to the local scale demands this definition.**

To define the most suitable coastal unit for the aims of this study we take into consideration the following guiding criteria:

- Consideration of the provisions of the ICZM Protocol and in particular the minimum limit of 100 m for the setback zone;
- Consideration of the administrative units to target the need for adaptation management;
- Inclusion of the direct effects of the watershed on the coastal stretch;
- Consideration of the spatial resolution of existing databases.

Definition of variables

We need to define classes for the variables used the application of the CRI-MED. We refer to the classes proposed by Satta (2014). The methodology proposed for the estimation of coastal risk to climate change impacts at the regional scale deals with qualitative and quantitative spatial attributes, representing physical, ecological and socioeconomic variables (Torresan et al., 2012; Satta, 2014).

According to various methodologies applied at the international level, the assignation of scores to vulnerability classes is performed using a 1–5 scale (Torresan et al., 2012; Satta, 2014). For each analysed impact, this scoring method allowed the definition of relative rankings within the subset of risk classes associated with each risk variable. **This means that the maximum**

score 5 is always assigned to the most important (i.e. higher) risk class and does not represent the maximum risk class in absolute terms (i.e. at the global scale). In the same way the minimum score 1 is assigned to the risk class that is considered the least important (i.e. the lowest risk class) in the subset of classes defined for each variable (Torresan et al., 2012). A description of each sub-index follows below.

The CRI-MED method is based on a scoring system of relative values for risk class, where:

1 = lowest risk

5 = highest risk

The Coastal Vulnerability Sub-Index

The Coastal Vulnerability Sub-Index is characterised by 4 variables:

- Landform
- Elevation
- Population Over 65
- Education Level.

Landform and Elevation describe the susceptibility of the coast to be affected by erosion and flooding generated or exacerbated by climate and non-climate drivers. The Landform variable is crucial to determine vulnerability and different classifications, related to coastal vulnerability assessment, exist in scientific literature (McLaughlin and Cooper, 2010; Abuodha & Woodroffe, 2010; Kunte et al., 2013; Torresan et al.; 2012). **The landform variable expresses the relative erodibility combined with the inundability of**

different landform types, coastal erosion and coastal flooding being the most important coastal hazards occurring in the Mediterranean costal zones.

Some other interesting landform categorizations are proposed by the Victorian State (DES, 2012) and the Western Australia Planning Commission[21]. In the framework of CLIMVAR, Vafeidis (2013) and PAP/RAC propose a specific categorization. All of them are reported in Table 3. To distinguish rocky coast in terms of their susceptibility to coastal hazards (e.g. erosion) we propose two categories: hard rocks (e.g. volcanic) and soft rocks (e.g. sedimentary). We do not consider the elevation of cliffs as this dimension is represented by the variable "elevation". Sandy shores represent the most susceptible landform to coastal hazards.

Table 3. Landform categories proposed in scientific literature

Authors	**Geogr. coverage**	**Vulnerability classes**				
		1	**2**	**3**	**4**	**5**
Ozyurt (2007)	Turkey	Rocky cliff coasts, fiords	Medium cliffs, indented coasts	Low cliffs, glacial drift, alluvial plain	Cobble beaches, estuary, lagoon	Barrier beach, sand beach, salt marsh, mudflats, deltas, mangrove, coral reefs
McLauhglin and Cooper (2010)	Ireland	High cliff (> 40 m)	Medium cliff (20 to 40 m)	Low cliff (10 to 20 m)	Shingle ridge/bar	Sand beach/dune
Abuodha and Woodroffe (2010)	Australia	High hard rock sea cliffs	Medium hard rock sea cliffs	Coastal re-entrant	Sandy shores backed by bedrock & artificial structures	Sandy shores backed by dunes and plains

[21] Western Australia Planning Commission - http://www.planning.wa.gov.au/674.asp (accessed 2014, December 15)

Vafeidis (2013)	Mediterranean	Rocky coast with pocket beaches	Limestone coast	Muddy	Unerodible or limited erosion	Sandy beach
PAP/RAC (2014) **ICZM plan for Šibenik region**	Šibenik region	Rocky coast	---	Peeble coast	Muddy coast	Artificial frontage

Based on existing categories we propose **a new categorization with the aim of reflecting the diversity of Mediterranean coastal zones geomorphology**, as reported in Table 4. Categories take into account susceptibility of different landform to erosion and to flooding.

Table 4. Landform categories proposed for this research

Landform		
Class	**Description**	**Score**
Hard Rock shores	Igneous rocks (e.g. diorite, gabbro, granite, basalts) and Metamorphic rocks (e.g. gneiss, phyllite, schist)	1
Soft Rock shores	Sedimentary Rocks (e.g. clastic sedimentary rocks such as breccia, conglomerate, sandstone; chemical sedimentary rocks such as rock salt and limestone; organic sedimentary rocks such as coal)	2
River deltas, estuaries and cobble beaches	Fluvial deltaic and estuarine areas are considered less vulnerable than sandy shores to eroding processes Cobble beaches are less vulnerable than Sandy Shores.	3
Sandy shores backed by bedrock or artificial structures and artificial frontage	Although the beach in front of bedrock or the artificial structure has the potential to undergo erosion in the event of climate forcing (e.g. SLR, Storms), further recession is likely to be constrained by the presence of bedrock or artificial structures.	4

	Artificial frontage can have a significant impact on sediment budgets and sediment transport, exacerbating coastal erosion and recession.	
Sandy shores backed by dunes and water plains	Lowland composed of sand shores and soil formations are highly susceptible to erosion. Water plains (e.g. saltmarshes, coastal lagoons and wetlands) are highly susceptible to erosion and flooding.	5

We apply this new categorization when analysing the coastline of the 11 Mediterranean countries selected for this study through GOOGLE EARTH and national geological maps. The result of this analysis is represented in the Landform map and contained **Annex 3**.

Several studies and researches on resilience to natural disaster risks show that age of population and education level represent two crucial indicators to estimate the resilience of coastal communities to cope with the adverse effects of coastal hazards. Frankenberg et al., (2013) found that better educated population are substantially more resilient to natural disasters and USACE (Guise, 2013) explained that elderly people are more difficult to evacuate/relocate during and after coastal flooding.

Table 5 presents the classes of the scores defined for the four variables.

Table 5. Variables for the CRI-MED Vulnerability Sub-Index

Coastal Vulnerability		
Variable	**Class**	**Score**
Landform (LF)	Sandy shores and water plains	5
	Sandy shores backed by bedrock or artificial structures and artificial frontage	4
	River deltas, estuaries and cobble beaches	3
	Soft Rock shores	2
	Hard Rock shores	1

Elevation (ELE) (m)	< 5	5
	6 - 10	4
	11 - 20	3
	21 - 30	2
	> 30	1
Population Over 65 (P65) (%)	> 20%	5
	20% – 14%	4
	13% – 8%	3
	7% – 3%	2
	< 3%	1
Education level (EDU) (%)	< 10%	5
	10% - 26%	4
	27% – 43%	3
	44% – 60%	2
	> 60%	1

The Coastal Forcing Sub-Index

The Coastal Forcing Sub-Index is characterised by 5 variables:

- Population growth
- Tourist arrivals
- Sea Level Rise
- Storms
- Drought

Given the difficulties in using climate scenario data from general circulation models (GCMs), many spatial Vulnerability and Risk Assessment applications use past climate variability or recent histories of extreme events as proxies for future changes (USAID, 2014). The underlying assumption is that those regions that are most affected by climate forcing today will likely have similar or greater levels of stress in the future (USAID, 2014). Vulnerability and risk assessment studies mapping must rely on accurate prediction of extreme events, in this regard GCMs have a limited ability to capture historical variance or future extremes (USAID, 2014). Whereas many Vulnerability and Risk Assessment methods include future climate driver scenarios, they generally do not include changes in non-climate driver's scenarios like population growth or tourism development (Preston 2012), which present considerable uncertainties, and are hard to predict. Concerning population growth patterns, efforts are now underway to develop scenarios for the shared socioeconomic pathways (SSPs) (Jones, 2013). The challenge of anticipating likely future population distributions can be rendered difficult by unanticipated economic or conflict events that can alter migration patterns (e.g. the so-called Arabic spring). **Because of the difficulty of projecting the socioeconomic drivers, the present risk assessment method extrapolates trend from past drivers variability.**

Increases of extreme sea levels due to rises in mean sea level and changes in storm characteristics are the dominant climate drivers for coastal changes and are of widespread concern (Nicholls et al., 2007; Burkett and Davidson, 2013). As for the rise of sea level there is a full scientific agreement at the international level, confirmed by the high number of observations, the same cannot be said for severe storms, extreme winds and extreme sea level (Satta, 2014).

In this work we focus on climate forcing that have direct physical impacts on coastal systems (e.g. erosion, coastal flooding) like SLR and extreme marine storms (Satta, 2014). In this sense, we do not consider SST and Ocean acidity that generate ecosystem effects (e.g. algae blooms). In fact low-lying coastal areas are more vulnerable to marine flooding during extreme sea level events caused by storm surges if it happens in combination with increased inland flows due to extreme rainfall (McInnes et al., 2009). An extreme marine storm can be also defined as an event where *"the wave* *height exceeds a given threshold during a certain time period"* (Mendoza and Jimenez, 2009). For the objective of this research we consider the Significant Wave Height (SWH) as a good proxy by which to measure storm intensity and impacts on the coast (Mendoza and Jemenez, 2009; Lionello, 2011; Gualdi et al*.*, 2013).

A significant methodological challenge is to map the frequency of extremes (e.g. SWH or Precipitation), due to data sparseness and gaps concerning for example problems with obtaining adequate meteorological station data (USAID, 2014).

Both extreme precipitation and droughts contribute to coastal hazards and in particular to flooding and erosion risk. In particular the joint effect of extreme precipitation with storm surges are forcing factors of coastal flooding (Lian et al., 2013). Runoff of precipitation collected by drainage systems flows directly or is pumped into the sea or into the water plains. Inland flooding, caused by extreme precipitation, has an influence on the drainage capability with a worse situation of flow backward, increasing the negative effects of coastal flooding generated by marine storms. Some evidence can be found to prove the existed dependence between precipitation and marine storms (Archetti et al., 2011; Zheng et al., 2013)

On the other side coastal erosion occurs where beaches that have been supplied with sediment carried down to the coast by rivers are depleted following a reduction in sediment yield to river mouths as a result of reduced runoff. Reduction of river flow due to droughts results in coastal erosion (Bird and Lewis, 2015). Both extreme precipitation and drought variables should be taken into account as relevant forcing factors. Considering the lack of models describing the extreme precipitations patterns for the whole Mediterranean basin (trends exist only for the northern shore of the Mediterranean, see EEA website) we do not consider the extreme precipitation variable for this work. Concerning the drought variable, a recent

NOAA analysis[22] investigated winter precipitation trends in the Mediterranean region for the period 1902 - 2010. The NOAA's team found that climate change and other processes contributed to the increase of drought frequency in the region. From such analysis it is possible to notice a strong increase of drought in regions like Morocco, Algeria, Syria, Israel, Palestine, Albania, Montenegro and Croatia (Dalmatia region) and a reduction just in Tunisia.

Table 6 shows the classes for the Forcing sub-index variables.

Table 6. Variables for the CRI-MED Forcing Sub-index

Coastal Forcing		
Variable	**Class**	**Score**
SLR (mm/y)	SLR > 3,2	5
	2,4 < SLR ≤ 3,2	4
	1,6 < SLR ≤ 2,4	3
	1< SLR ≤ 1,6	2
	SLR ≤ 1	1
Storms (SWH) (cm)	SWH > 350	5
	250 < SWH ≤ 3500	4
	150 < SWH ≤250	3
	50 < SWH ≤ 150	2
	SWH ≤ 50	1
Droughts (DRO) (mm)	DRO < -36	5
	-36 < DRO ≤ -12	4
	-12 < DRO ≤ 12	3
	12 < DRO ≤ 36	2
	DRO >36	1
Population growth (PGR)	PGR >2%	5
	1% < PGR ≤ 2%	4

[22] NOAA- http://www.noaanews.noaa.gov/stories2011/20111027_drought.html (accessed 2015, January 15).

	0,5% < PGR ≤ 1%	3
	0,1% < PGR ≤ 0,5%	2
	PGR ≤ 0,1%	1
Tourist arrivals (TOUR)	TOUR > 10%	5
	5% < TOUR ≤ 10%	4
	1% < TOUR ≤ 5%	3
	0 % < TOUR ≤ 1%	2
	TOUR ≤ 0 %	1

The Coastal Exposure Sub-Index

The Coastal Exposure Sub-Index is characterised by 2 variables:

- Land Cover
- Population density.

Land Cover indicates the coastal assets at risk. The highest value is attributed to the LC category "urban areas", which includes residential, commercial, industrial, transportation, communications, utilities, and mixed urban built-up areas. The lowest value is attributed to "bare areas". The Land Cover variable alone does not explain the magnitude of the population at risk for a specific area. It just describes the presence human activities but it does not distinguish between high and low populated areas. **For this reason we need to add another variable, which describes the Population Density per squared km.**

By adding the scores of the two variables it is possible to better differentiate the coastal asset in terms of population at risk.

In Table 7 the classes for the Forcing sub-index variables are presented.

Table 7. Variables for the CRI-MED Exposure Sub-index

Coastal Exposure		
Variable	**Class**	**Score**
Land Cover (LC)	Urban areas	5
	Agriculture	4
	Forest and Water bodies	3
	Shrub land, grasslands, Sparse vegetation	2
	Bare areas	1
Population Density (PDE) (population /Km2)	PDE > 250	5
	100 < PDE ≤ 250	4
	50 < PDE ≤100	3
	25 < PDE ≤ 50	2
	PDE ≤ 25	1

Calculation of the CRI-MED score

The formulas to derive the three sub-indexes are as follow:

$$\text{Coastal Vulnerability (CV) sub-index} = \{[(S_{LF} + S_{ELE} + S_{P65} + S_{EDU}) - 4] / 16\}$$

S_{LF} = score of Landform variable: S_{ELE} = score of elevation variable: S_{P65}= score of pop over 65 variable: S_{EDU} = score of education level variable.

$$\text{Coastal Forcing (CF) sub-index} = \{[(S_{SLR} + S_{SWH} + S_{DRO} + S_{PGR} + S_{TOUR}) - 5] / 20\}$$

S_{SLR} = score of SLR variable; S_{SWH} = score of SWH variable; S_{DRO} = Score of Droughts variable; S_{POP} = score of POP variable; S_{TOUR} = score of TOUR variable.

We adjust the formula to calculate the CE score to always get values > 0.

$$\text{Coastal Exposure (CE) sub-index} = \{[(S_{LC} + S_{PDE}) - 1] / 9\}$$

The final score for the CRI-MED index with weighted variables is still calculated multiplying the three sub-index values, as shown in the formula below:

$$\text{CRI-MED} = CV \times CF \times CE.$$

Building the CRI-MED spatial index

As mentioned above, the CRI-MED spatial index combines multiple variable layers, representing different aspects of risk, in sub-indexes (vulnerability, forcing and exposure) layers, in such a way that risk "hot-spots" as well as areas of relatively lower risk emerge from the integration of the layers (USAID, 2014).

The CRI-MED, referring to the Multi-scale Coastal Vulnerability Index proposed by McLaughlin and Cooper (2010), is based on an additive approach, where the first step is normalization of the variables.

The values for each variable, represented by a layer, are normalized to a consistent ordinal or unit-less scale (e.g., population over 65, on a scale from 1–5, from lowest to highest). The scaled layers are then averaged or added together to come up with a score referring to its contribution to coastal risk.

One advantage of this approach is that separate maps for each risk component (vulnerability, forcing, exposure) allows supporting decision-makers to analyse adaptation options (USAID, 2014). The relatively high degree of transparency of these methods represents a clear advantage. On the other side, the method must face important challenges concerning how to weigh the variables, since the weighing will ultimately affect the visualization and interpretation of results (USAID, 2014).

A key issue of this technical report is that the data and methods used in spatial risk assessment are clearly documented, and that map and other information on uncertainties and assumptions are included as part of the risk mapping.

Measuring the CRI-MED Variables

The technical description, database and sources related to the variables used to build the CRI-MED are presented below in more detail.

Coastal Vulnerability Sub-Index variables

LANDFORM (LF)

Description: Expresses the relative erodibility combined with the inundability of different coastal landform types.

Database: Own database derived from analysis of the coastal landform of the 11 Mediterranean countries according to a proposed categorization. The resulting map is showed in Annex 3.

Source: Google Earth and national geological maps to distinguish the rock characteristics.

ELEVATION (ELE)

Description: The SRTM 90m DEM's is a Digital elevation models that covers all world countries, with a resolution of 90m at the equator, and it's provided in mosaiced 5 deg x 5 deg tiles available in both ArcInfo ASCII and GeoTiff format. The SRTM digital elevation data provided by the Consortium for Spatial Information (CGIAR-CSI) has been processed to fill data voids.

Database: Consortium for Spatial Information: (http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp).

Source: The digital elevation models, produced by NASA Shuttle Radar Topographic Mission (SRTM).

POPULATION OVER 65 (P65)

Description: Population ages 65 and above as a percentage of the total population. Population is based on the *de facto* definition of population, which counts all residents regardless of legal status or citizenship--except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of the country of origin.

Database: The World Bank: (http://data.worldbank.org/indicator).

Source: The United Nations Population Division's World Population Prospects.

EDUCATION LEVEL (EDU)

Description: Gross enrolment ratio. Tertiary (ISCED 5 and 6) is the total enrollment in tertiary education (ISCED 5 and 6), regardless of age, expressed as a percentage of the total population of the five-year age group following on from secondary school leaving.

Database: The World Bank: (http://data.worldbank.org/indicator).

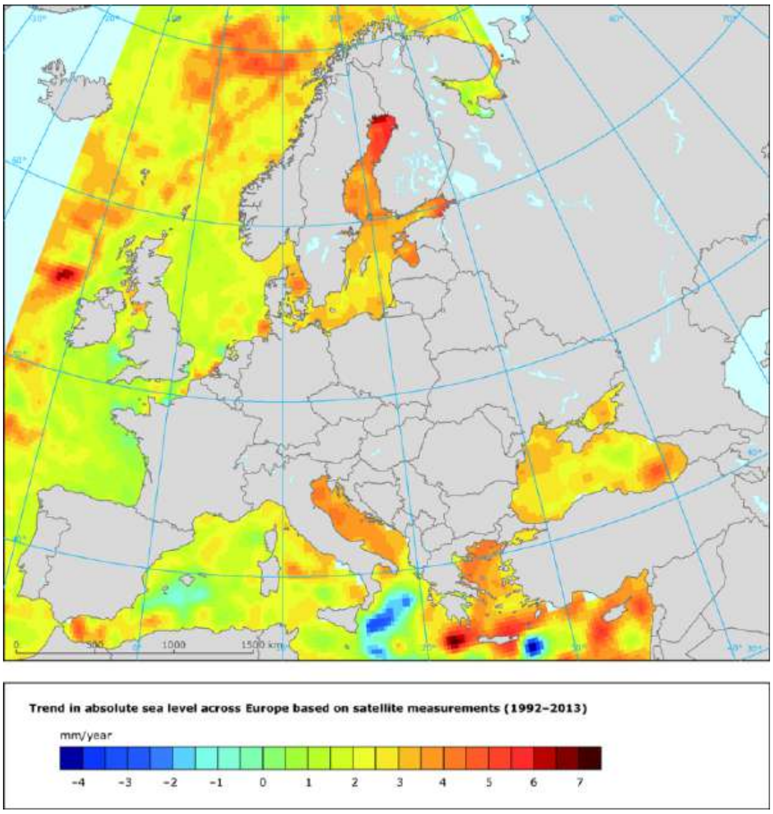
Source: UNESCO Institute for Statistics.

Coastal Forcing Sub-Index variables

SEA LEVEL RISE (SLR)

Description: The simplest way to define the SLR forcing variable is to determine how much the level of the sea increases in one year, with a value expressed in cm/year. The choice of data for the SLR variable largely depends on the scale of application of the risk assessment method (Satta, 2014). In the Mediterranean we have two types of mean sea level observations: tide gauges that go back to the late nineteenth century but only with local measurements, and satellite altimetry available since 1992 (Gualdi et al., 2013). Satellite altimetry data provides accurate measures from the regional to the local level for a limited time range. In the case of the Mediterranean this range is 20 years.

Figure 4. Trend in absolute sea level in European Seas based on satellite measurements (1992–2013) (Source: EEA, 2014)



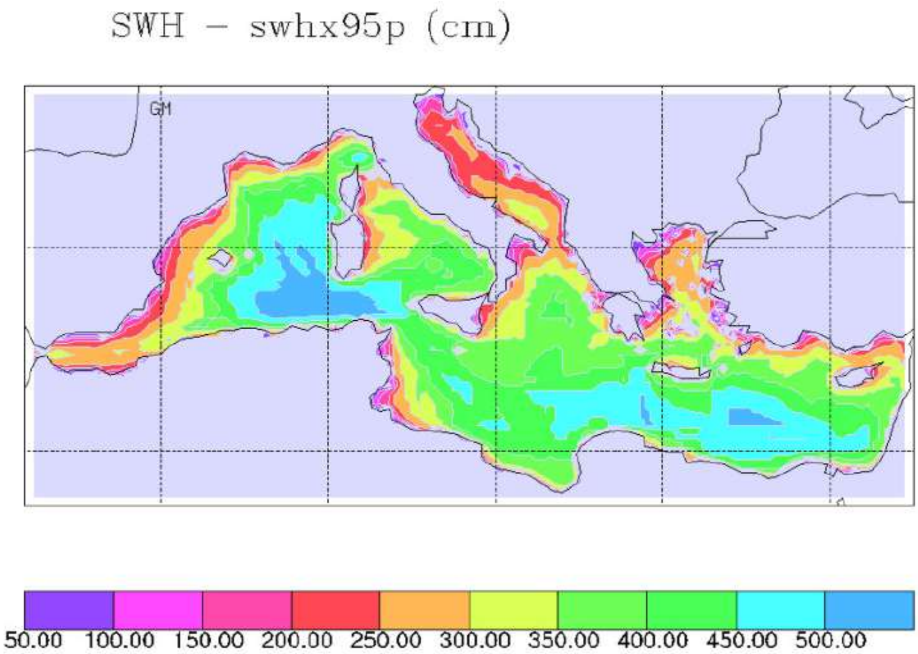
Database: AVISO - http://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/products-images.html (accessed 2015, January 18).

Source: TOPEX/Poseidon, Jason-1 and Jason-2.

STORMS (SWH)

Description: According to Mendoza & Jimenez (2011) a storm can be considered as an extreme atmospheric perturbation accompanied by strong winds, the effects of which are an increase in wave height and sea level (Satta, 2014). Storms in terms of climate forcing can be described as an event where *"the wave height exceeds a given threshold during a certain time period"* (Mendoza & Jimenez, 2009). For the objective of this work we consider the Significant Wave Height as a good proxy by which to measure storm intensity and impacts on the coast (Satta, 2014). In particular, to estimate the trend of severe storm changes in the Mediterranean we propose to define the Storms forcing variable (ST) as the average number of detected SWH above 95 percentile / year (SWHx95p). This variable represents the number of records/events on which a value falls above or below a fixed threshold SWHX95p, defined as the number of events exceeding the long term (e.g. return period Tr = 100 years) 95 percentile of daily SWH (Satta, 2014). Values are represented in Figure 6.

Figure 6. Number of events exceeding the long term (e.g. return period Tr = 100 years) 95 percentile of daily significant maximum wave in the Mediterranean (Source: Pino et al., 2009)



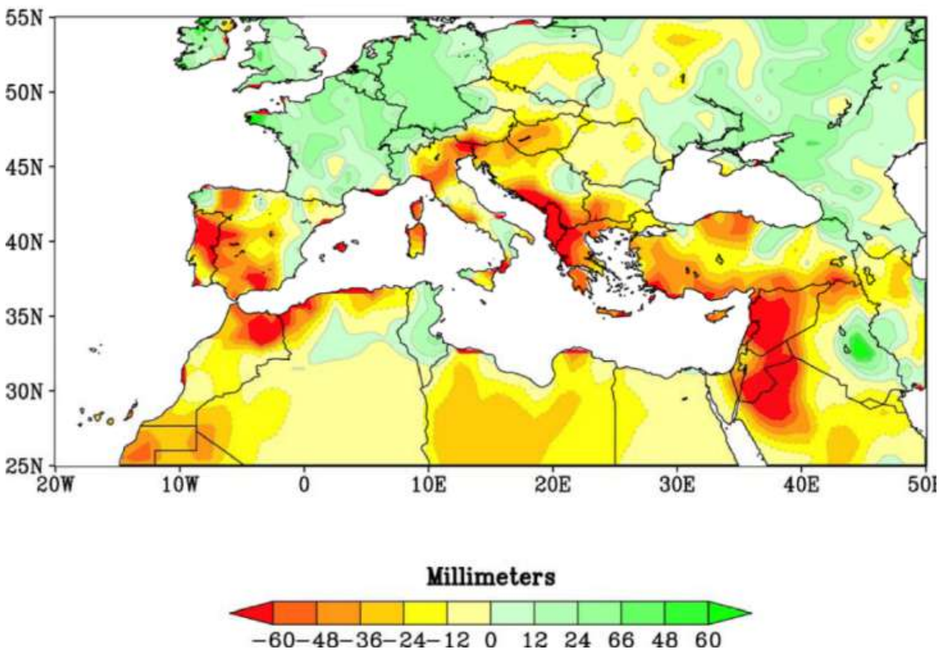
Source: Pino et al. (2009) have elaborated the frequency of events above this fixed threshold computed with reference to a long-term (1940-2002) period 95 percentile, but for short (1-5 year long) time intervals. The SWHx95p has been plotted for all the Mediterranean (Figure 6).

Note: The map resulting from the work of Pino, never published, is available in Lionello (2011). The values were extracted from a hind cast of waves and show the spatial distribution of empirical percentiles of the distribution. Even if this work represents a unique example of SWHx95p measures for the Mediterranean it has never been validated which means very high uncertainties. The map created by Pino (2009) has been adjusted and elaborated to approximate the coastal line. Further research is needed for more accurate modeling of SWH95p distribution in the Mediterranean.

DROUGHTS (DRO)

Description: This variable is based on a recent NOAA analysis, regarding the winter precipitation trends in the Mediterranean region for the period 1902 - 2010. The NOAA's team found that climate change and other processes contributed to the increase of drought frequency in the region. The map in Figure 6 shows Mediterranean regions that experienced significantly drier winters during 1971-2010 in comparison to the period 1902-2010. The variable is expressed in mm; reds and oranges highlight drier areas around the Mediterranean (NOAA, 2011).

Figure 7. Mediterranean regions that experienced drier winters in 1971-2010 compared to the past (source: NOAA, 2011)



Database: NOAA-http://www.noaanews.noaa.gov/stories2011/20111027_drought.html (accessed 2015, January 15).

Source: NOAA website.

POPULATION GROWTH (PGR)

Description: Population growth (annual %) is the exponential rate of growth of midyear population from year t-1 to t, expressed as a percentage.

Database: The World Bank: (http://data.worldbank.org/indicator).

Source: Derived from total population. Population source: (1) United Nations Population Division. World Population Prospects, (2) United Nations Statistical Division. Population and Vital Statistics Report (various years), (3) Census reports and other statistical publications from national statistical offices, (4) Eurostat: Demographic Statistics, (5) Secretariat of the Pacific Community: Statistics and Demography Programme, and (6) U.S. Census Bureau: International Database.

TOURIST ARRIVALS (TOUR)

Description: International inbound tourists (overnight visitors) are the number of tourists who travel to a country other than that in which they have their usual residence, but outside their usual environment, for a period not exceeding 12 months and whose main purpose in visiting is other than an activity remunerated from within the country visited.

Database: The World Bank: (http://data.worldbank.org/indicator).

Source: UNESCO Institute for Statistics.

Note: When data on number of tourists are not available, the number of visitors, which includes tourists, same-day visitors, cruise passengers, and crewmembers, is shown instead. Sources and collection methods for arrivals differ across countries. In some cases, data are from border statistics (police, immigration, and the like) and supplemented by border surveys. In other cases, data are from tourism accommodation establishments. For some countries, the number of arrivals is limited to arrivals by air and for others to arrivals staying in hotels. Some countries include arrivals of nationals residing abroad while others do not. Caution should be used in comparing arrivals across countries. The data on inbound tourists refer to the number of arrivals, not to the number of people traveling. Thus a person who makes several trips to a country during a given period is counted each time as a new arrival.

Coastal Exposure Sub-Index variables

LAND COVER (LC)

Description: Land Cover (LC) project of the Climate Change Initiative (CCI) led by the European Space Agency (ESA). The LC map from 2010 is a global land cover map at 300m spatial resolution produced considering a reference period from 2008 to 2012 using MERIS 10-year LC map as baseline and SPOT-VGT time series for updating. The Coordinate Reference System (CRS) used for the global land cover databases is a geographic coordinate system (GCS) based on the World Geodetic System 84 (WGS84).

Database: ESA (http://maps.elie.ucl.ac.be/CCI/viewer/index.php).

Source: CCI-LC project.

Table 8. Land cover legend and score

Coastal Exposure		
Class	**Description**	**Score**
10	Cropland, rainfed	4
11	Herbaceous cover	
12	Tree or shrub cover	
20	Cropland, irrigated or post-flooding	
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)	
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)	3
50	Tree cover, broadleaved, evergreen, closed to open (>15%)	
60	Tree cover, broadleaved, deciduous, closed to open (>15%)	

61	Tree cover, broadleaved, deciduous, closed (>40%)	
62	Tree covers, broadleaved, deciduous, open (15-40%)	
70	Tree cover, needleleaved, evergreen, closed to open (>15%)	
71	Tree cover, needleleaved, evergreen, closed (>40%)	
72	Tree cover, needleleaved, evergreen, open (15-40%)	
80	Tree cover, needleleaved, deciduous, closed to open (>15%)	
81	Tree cover, needleleaved, deciduous, closed (>40%)	
82	Tree cover, needle leaved, deciduous, open (15-40%)	
90	Tree cover, mixed leaf type (broadleaved and needleleaved)	
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	
120	Shrubland	2
121	Evergreen shrubland	
122	Deciduous shrubland	
130	Grassland	
140	Lichens and mosses	
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)	
152	Sparse shrub (<15%)	
153	Sparse herbaceous cover (<15%)	
160	Tree cover, flooded, fresh or brackish water	
170	Tree cover, flooded, saline water	
180	Shrub or herbaceous cover, flooded, fresh/saline/brackish water	
190	Urban areas	5
200	Bare areas	1
201	Consolidated bare areas	
202	Unconsolidated bare areas	
220	Permanent snow and ice	

POPULATION DENSITY (PDE)

Description: The population density variable measures population per square km. The population values are extrapolated based on a combination of subnational growth rates from census dates and national growth rates from United Nations statistics. All of the grids have been adjusted to match United Nations national level population estimates. The population density grids are derived by dividing the population count grids by the land area grid. PDE represents population per Km^2.

Database: Gridded Population of the World, Version 3 (GPWv3), Future Estimates consists of estimates of human population for the years 2005, 2010, and 2015 by 2.5 arc-minute grid cells. A proportional allocation gridding algorithm, utilizing more than 300,000 national and sub-national administrative units, is used to assign population values to grid cells. The grids are available in various GIS-compatible data formats and geographic extents (global, continent [Antarctica not included], and country levels).

Source: Center for International Earth Science Information Network - CIESIN - Columbia University, and Centro Internacional de Agricultura Tropical - CIAT. 2005. Gridded Population of the World, Version 3 (GPWv3): Population Density Grid, Future Estimates. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4ST7MRB. Accessed 19th January 2015.

Weighing the variables

The selected variables contribute in a different way to the hazards affecting Mediterranean coastal zones. To disentangle the weight of each variable in generating the coastal risk, we analyse the direct (or indirect) effects of each variable to the coastal hazards. Erosion, flooding and saltwater intrusion (SWI) have been identified as the key hazards impacting Mediterranean coastal zones (Hemming et al., 2013).

Climate and non-climate changes in the Mediterranean are unlikely to create new coastal hazards, but at many locations they will exacerbate existing hazards. This could result in increased rates of coastal erosion, more extensive and frequent coastal flooding and increasing intrusion of seawater into estuaries and coastal aquifers (DES, 2012). Table 8 shows the sensitivity of coastal hazards to different variables of Forcing, Vulnerability and Exposure factors. According to our own evaluation we assign the relative weights that are reported in the last column of Table 9. SLR, SWH, LF and ELE represent the most significant variables in terms of their influence in generating coastal risk. The variables P65 and EDU represent the resilience of the coastal communities to adapt to change and their capacity to cope with the adverse effects of coastal hazards. These variables play a role in counterbalancing (or reducing) the negative effects of coastal hazards but they cannot nullify the coastal risk and therefore we assign a lower weight.

Table 9. Sensitivity of coastal hazards to different variables

	EROSION	FLOODING	SWI	WEIGHT
Vulnerability Sub-Index				
Landform	H	H	H	35%
Elevation	H	H	H	35%
Population over 65	L	M	M	15%
Education level	L	M	M	15%
Forcing Sub-Index				
SLR	H	H	H	30%
SWH	H	H	H	30%
Droughts	M	L	M	10%
Population trend	H	L	H	20%

Tourism trend	M	L	M	10%
Exposure Sub-Index				
Land Cover	H	H	H	70%
Population density	H	H	H	30%

Legenda: L = Low, M = Medium, H = High

CRI-MED Index calculation with weighted variables

In order to include the weights of each variable, the formulas to calculate the sub-index are modified as follows:

$$\text{Coastal Vulnerability (CV) sub-index} = \{[(W_{LF} * S_{LF} + W_{ELE} * S_{ELE} + W_{P65} * S_{P65} + W_{EDU} * S_{EDU}) - 1] / 4\}$$

Where: S_{LF} = score of LF variable: S_{ELE} = score of ELE variable: S_{P65} = score of P65 variable; S_{EDU} = score of EDU variable; W_{LF} = weight of LF variable; W_{ELE} = weight of ELE variable; W_{P65} = weight of P65 variable; W_{P65} = weight of P65 variable; W_{EDU} = weight of EDU variable.

$$\text{Coastal Forcing (CF) sub-index} = \{[(W_{SLR} * S_{SLR} + W * S_{SWH} + W * S_{DRO} + W * S_{PGR} + W_{TOUR} * S_{TOUR}) - 1] / 4\}$$

Where: S_{SLR} = score of SLR variable; S_{SWH} = score of SWH variable; S_{DRO} = Score of DRO variable; S_{POP} = score of POP variable; S_{TOUR} = score of TOUR variable; W_{SLR} = weight of SLR variable; W_{SWH} = weight of SWH variable; W_{DRO} = weight of DRO variable; W_{PGR} = weight of PGR variable; W_{TOUR} = weight of TOUR variable

$$\text{Coastal Exposure (CE) sub-index} = \{(W_{LC} * S_{LC} + W_{PDE} * S_{PDE}) / 5\}$$

Where: S_{LC} = score of LC variable; S_{PDE} = score of PDE variable; W_{LC} = weight of LC variable; W_{PDE} = weight of PDE variable.

The score of the CRI-MED index is still computed multiplying the three sub-index scores.

We calculate the CRI-MED index using the function "Raster calculator", which allows performing calculations on the basis of existing pixel values and obtain the results written into a new raster layer. Almost all the values have been assigned on the attribute table of each shapefile.

For the variables P65, EDU, TOUR, and PGR, we assign a constant value on national scale, while for LF, SWH, DRO, and PDE, the coastline has been split depending on coastal characteristics or conditions.

In order to allow a clear visualization of the risk index into risk maps, the risk values of CRI-MED, ranging from 1 to 5, are categorized into 5 qualitative subclasses (i.e. very high, high, medium, low and very low).

Once we assign to all the elements of each shapefile the corresponding value (from 1 to 5), we converted them in raster images, one raster for each variable of coastal vulnerability, coastal forcing and coastal exposure, with a cell size of 300 meters.

The values for the variables elevation, land cover, and sea level rise, have been instead extracted directly from the pixel value of specific raster images. We used an "Extraction tool" that allowed us to select and extract a subset of cells from each raster, by their spatial location.

In order to reduce to the minimum the number of cell containing "no data", due to the different images resolution, we analyzed and correct some void cell (corresponding to cell covered by the sea) using the closest available pixel value, before proceeding to the extraction tool.

In particular, for the DEM images we firstly had to "mosaic" the tiles, covering the studied area, then aggregate the cells to have a reduced-resolution version of the raster, increasing the cell size from 90 meters to 300 meters. Each output cell contained the mean value of the input cells that are encompassed by the extent of that cell.

Results are summarized in coastal risk maps that are presented and discussed in the next section.

Applying the CRI-MED

Main results

The application of the CRI-MED methodology to the eleven Mediterranean countries selected for the project ClimVar & ICZM led to **a ranking of the relative risk of each coastal region in relation to potential coastal hazards (coastal erosion, coastal flooding and saltwater intrusion) generated and/or exacerbated by climate and non-climate forcing**.

The CRI-MED methodology, proposed for the regional coastal risk assessment, can represent a useful tool to support decision-makers in the spatial identification of the coastal areas characterized by different vulnerability and exposure levels and in the definition of adaptation options.

Risk variables associated to vulnerability, exposure and forcing are aggregated according to the coastal risk function. **The resulting risk maps represent the visualization and prioritization of risk in the coastal zones**. The final risk rankings are dimensionless numbers that judge the relative degree of risk of coastal zones to each analyzed coastal hazard, in relation to qualitative risk classes (i.e. extremely high, high, medium, low, extremely low). In this sense, higher risk values do not imply high risk in absolute terms, but only compared to other case coastal zones.

The CRI-MED method allows a comparative analysis of the coastal regions the 11 participating Mediterranean countries.

The score derived from the calculation for the CRI-MED spatial index applied to each pixel is the summation of the scores resulting from heterogeneous variables.

With the aim to produce a qualitative ranking of risk in the considered coastal zones visualized by means of relative risk maps, all variable data layers were assigned a risk score and a weight, according to the procedure described in the previous sub-sections. The CRI-MED equation with weighted variables has been applied to each cell (300m X 300m) of the coastal study area grid for a total of 52.350 cells.

The main goal of this project specifically refers to the need of selecting coastal hot-spots in the participating Mediterranean countries. **In the present study the coastal hot-spots are identified through a statistical analysis (i.e. clusters of cells with high risk values) and the CRI score is used to identify where cells with either high or low risk values cluster spatially** (Torresan et al., 2012).

To be considered a statistically significant hot-spot, a cell must have a high-risk value and be surrounded by other cells with high risk values as well.

The scores for each pixel are calculated using the function "Raster calculator", which allows performing calculations on the basis of existing pixel values and obtain the results written into a new raster layer. The GIS application implementing the CRI scores works by looking at each cell within the context of neighboring cells. **The risk scores obtained applying the Raster Calculator to the whole study area range from 0.02 to 0.79.**

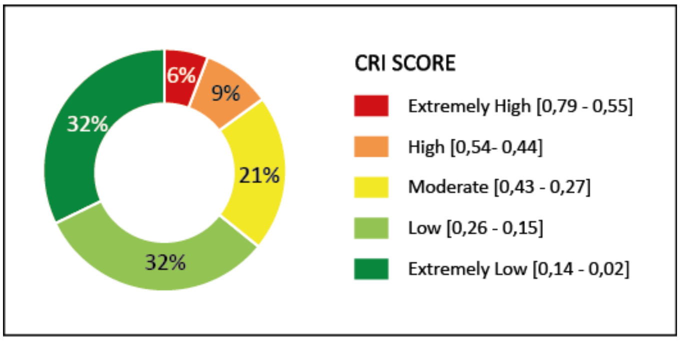
To classify the scores obtained for each cell, we can use one of many standard classification methods provided in ArcGIS Pro. Classification methods are used for defining geostatistical layers or for classifying numerical fields for graduated symbology. The method used for this work is the "Natural Breaks" grouping method. Natural Breaks classes are based on natural groupings inherent in the data. Choosing the class breaks that best group similar values and that maximize the differences between classes identifies break points. The cell values are divided into classes whose boundaries are set when there are relatively big jumps in the data values (ARCGIS website, 2015). This classification is based on the Jenks' Natural Breaks algorithm.

The classes obtained with the "Natural Breaks" method are reported in Table 10.

Table 10. Qualitative risk classes defined with the "Natural Breaks" method

Risk class	CRI Score	Number of cells	% of the total
Extremely High	0,79 - 0,55	3.283	6%
High	0,54 - 0,44	4.772	9%
Moderate	0,43 - 0,27	10.941	21%
Low	0,26 - 0,15	16.542	32%
Extremely Low	0,15 - 0,02	16.812	32%

Figure 8. Statistical distribution of risk classes



As shown in Figure 8, a considerable number of cells represent extremely low and low risk values (64% in total), as opposed to moderate risk (21%), high risk (9%) and extremely high risk values (6%) values.

Specifically, almost 94% of the scores obtained for the whole study area are lower than 0.55. This means that there is a very limited presence of cells characterized by relatively high risk values that can form clusters. **We consider that these statistically significant CRI scores (CRI≥0.55) identify hot-spots i.e. areas with extremely high risk values.** Statistically significant low CRI scores (CRI<0.15) identify clusters with extremely low risk values.

The Regional Risk Assessment Map for the assessment of coastal risk to climate and non-climate forcing, displaying the result in terms of qualitative risk classes is presented in Figure 9. The map shows the values of risk assumed by each cell by applying the equation defined for the method CRI-MED. Cells that assume "extremely high risk" values are indicated in red and in the context of this study these are defined as "hot-spots". The map clearly shows that a relatively small number of areas in the Mediterranean region is to be considered most at risk.

In order to better identify the hot-spots obtained from the CRI-MED application, we refer to the maps included in Annexes 4 - 13 that present a zooming on national coastal zones for all the Mediterranean countries involved in this study.

At this stage it is therefore possible to list the identified coastal hot-spots per country. Noting that areas at extremely high risk are predominantly located in the southern Mediterranean region, the countries concerned by coastal hot-spots include Morocco, Algeria, Libya, Egypt, Palestine, and Syria.

Other countries in the region show areas at high risk, indicated in orange in the map, for instance in Albania and other Adriatic coastal sites. It is important to clarify that if we had looked at high risk in addition to extremely high risk, the final results would have looked different and the number of hot-spots would be larger. However, as per methodological assumptions the hot-spot threshold was set in a way to highlight only areas that appear *exceptionally* at risk according to the statistical distribution of cells, where areas at high risk are located next to areas that are also at high risk.

List of national coastal hot-spots identified

- ***Morocco: Tetouan, Nador, Saidia***
- ***Algeria: Ain El Bia, Tenes, Zeralda, Tassoust, Annaba***
- ***Libya: Tripoli, Misrata, Benghazi, Darianah, Tocra and Ad Dirsiyah,***
- ***Egypt: Sidi Barrani, Marsa Matrouth, Alexandria, Baltim, Ras El Bar, Port Said, Al Arish***
- ***Palestine: the Northern shore of Gaza Strip***
- ***Syria: the shore from Al Hamidiyah to Tartus, the shore from Tartus to Marqueh, Baniyas, the shore from Jable to Latakia, Om Al Toyour, Ummetli.***

Figure 9. Regional Risk Assessment Map for the Mediterranean

Discussion of results

The risk assessment approach highlights some substantial differences with the traditional vulnerability assessment methods. Risk depends on the interaction of vulnerability, forcing and exposure. If vulnerability is high but forcing or/and exposure is low, risk is low.

With the aim to understand the key differences between the two methods of assessment, and in particular some limitations of the methods based just on vulnerability, we propose to explore the application of the CRI-MED methodology in two coastal destinations considered "vulnerable" by the recent scientific literature: the Nile Delta and the Gulf of Gabes. These two coastal zones have been intensively studied in scientific literature and are commonly recognized as high vulnerable areas.

Within the framework of the project CIRCE, eleven case study locations were selected to reflect three generic environments (urban, rural, and coastal), to quantify current and future climate change and to assess the potential important consequences for human communities and ecosystems at the regional to local scales. Among the coastal case studies presented in the third volume of the Regional Assessment of Climate Change in the Mediterranean (Navarra and Tubiana, 2013 c) the Nile Delta and the Gulf of Gabes have been assessed in terms of their vulnerability to the impacts of climate change.

As widely discussed in the previous sections, the risk index is obtained by multiplying the vulnerability sub-index with the forcing sub-index and the exposure sub-index. The CRI-MED allows to obtain the relative values of forcing, vulnerability and exposure and to represent them in specific maps. **The maps for risk, forcing, vulnerability and exposure for the two coastal zones are presented in Figure 10.**

First of all, we consider the maps obtained measuring the variables of the Vulnerability Sub-Index (Figure 10, A1 and A2). Both zones show high and extremely high vulnerability values (respectively orange and red colored segments). High vulnerability is mainly due to beaches landform and low elevation, which characterize the two zones. Looking at the vulnerability map, areas with higher vulnerability are characterized by low elevation (e.g. alluvial plains) and beaches landform. Using the definition of vulnerability proposed by IPCC (2014) and adopted for this work, we can conclude that the two areas present a high propensity to be adversely affected.

Secondly, we consider the coastal forcing maps produced displaying the values calculated with the Forcing Sub-Index (Figure 10, B1 and B2). In terms of forcing, the two areas have been studied extensively by Sanchez-Arcilla et al. (2011). The values of SLR stated in the project CIRCE (Sanchez-Arcilla et al., 2011), correspond to data from satellite altimetry used in this work. Concerning SWH, Sanchez-Arcilla et al (2011) evaluated this parameter only for the Gulf of Gabes. In this study it was considered the SWH trend in the period 1974-1994.

Thirdly, we consider the coastal exposure map (Figure 10, C1 and C2). The Exposure Sub-Index is characterized by land cover and population density. Considering the map produced with the Exposure Sub-Index, we see that the urban areas of Alexandria and Port Said in the Nile Delta and the city of Gabes in the Gulf of Gabes, show extremely high values of exposure. The other coastal areas show moderate to very low values.

Finally, we analyze the Risk Map (Figure 10, D1 and D2). Just three spots present extremely high-risk values and they are all in the Nile Delta, namely: Alexandria, Ras El-Bar and Port Said. The Gulf of Gabes shows from extremely low to moderate levels of risk. Moderate risk corresponds to the city of Gabes and to Djerba where coastal exposure is high.

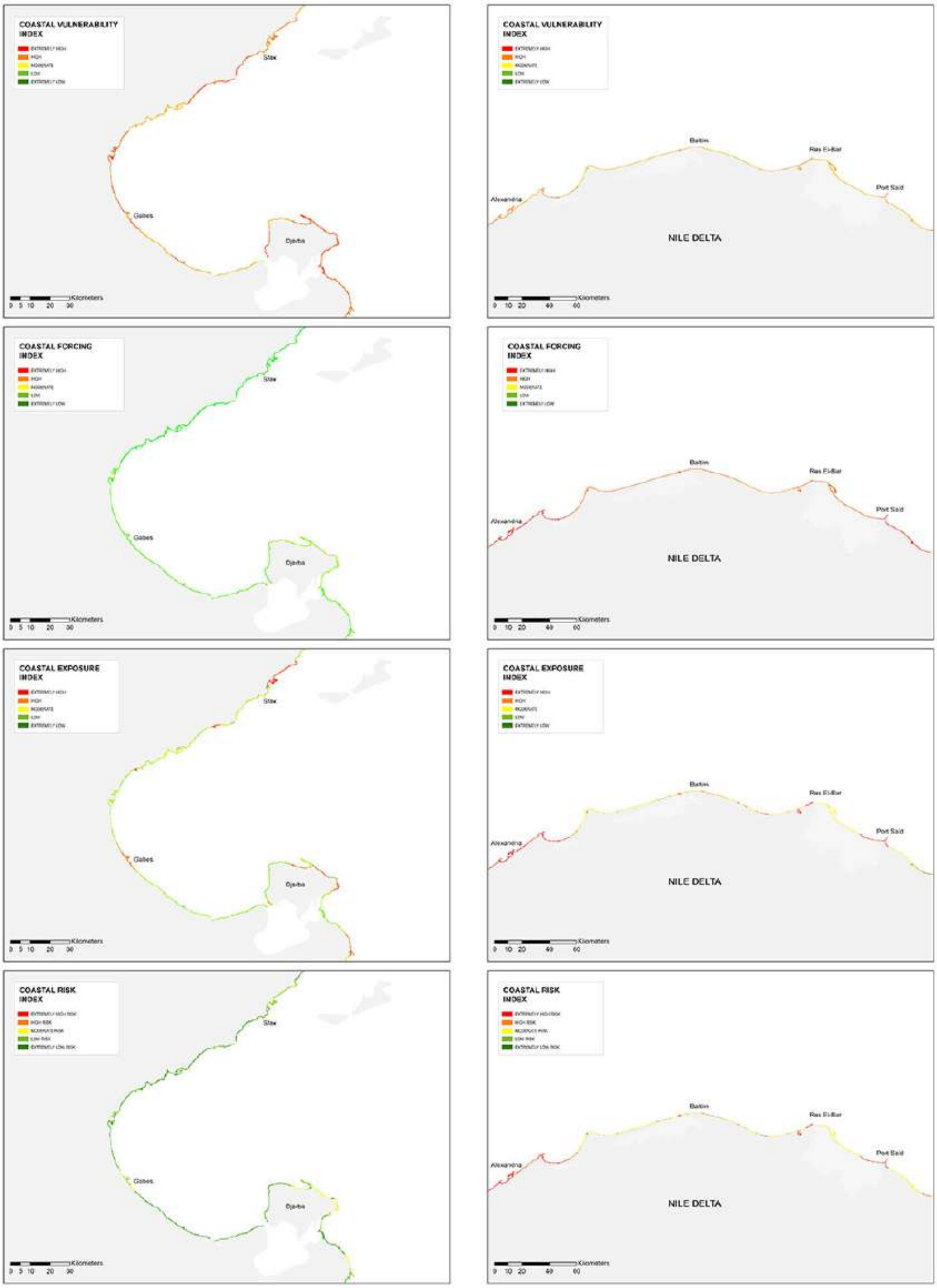
The two coastal areas show substantially different values in terms of forcing. The area of the Nile Delta is subject to an extremely high forcing (both climatic and non-climatic) while the area of the Gulf of Gabes shows a low forcing according to the categories defined for this work.

As a final step of this exercise, two research questions remain to be answered: (1) whether the vulnerability assessment approach allows describing the effects of climate change on coastal zones; and (2) whether knowing the coastal vulnerability represents a sufficient condition to determine the best options for adaptation to the impacts generated by climate change.

With respect to the first issue, knowing the level of vulnerability allows saying that, theoretically, the coastal areas characterized by high values of vulnerability are potentially at risk but this risk will materialize only in the presence of high values of forcing and exposure. **This means that only if a particular level of climate (and non climate) forcing exists in an area where there is an exposed coastal asset (e.g. urban area), vulnerability becomes risk for which adaptation measures are needed.**

Consequently, it is possible to answer the second question. The only knowledge of the level of vulnerability for each cell is not a necessary and sufficient condition for defining the spatial extent and intensity of the climate change impacts. **In addition to vulnerability, it is necessary to know the values of the forcing and exposure associated with each cell. Designing and implementing adaptation strategies based on coastal vulnerability might be useless and most of all represent a waste of resources.**

Figure 10. Vulnerability maps (A1 and A2), Forcing maps (B1 and B2), Exposure maps (C1 and C2), and Risk maps (D1 and D2) for the Gulf of Gabes (left) and of the Nile Delta (right)



In summary, the study shows that the coastal areas characterized by high vulnerability and exposure do not necessarily present high levels of risk. This is specifically demonstrated by the case of the Gulf of Gabes, where, due to the low value of forcing, low values of risk are measured. Notwithstanding the low forcing, the urban area of the city of Gabes presents a moderate level of risk. Particularly important is the role of the variable "population density". A higher value of population density means in fact that the risk in terms of exposed population is higher. Both the city of Gabes and Alexandria fall into the category of land use "urban". The higher population density of Alexandria compared to Gabes makes the former more exposed to climate forcing, therefore most at risk.

In the area of the Nile Delta there are several areas showing extremely levels of risk including Alexandria, Ras-El-Bar and Port Said. According to the definition proposed in this work these areas can be defined hot-spots.

Conclusions

Limitations and future improvements

The present work adequately takes into account the best available geographical information at the Mediterranean scale, thus requiring a great effort to deal with a huge amount of data at a detailed spatial resolution. Where geo-referenced information was not available, as in the case of variable landform, this was built from scratch by analyzing the geomorphology of coastal areas by GOOGLE EARTH and by national geological and geomorphological maps. One of the most challenging issues that we experienced while performing the regional risk assessment relates to the collection and interpretation of data drawn from different databases, and their transformation into homogeneous formats for the eleven Mediterranean countries involved in the project. Moreover, the heterogeneity of such databases required a huge work of managing data with different geographic coordinate systems to allow the GIS processing.

The main scientific uncertainties related to the regional risk assessment concern the homogenization of different databases and on the approximation of the shoreline with the 300x300 pixels generating geometrical errors in terms of "no data" areas. Some uncertainties could be identified and corrected by carrying on a sensitivity analysis with other risk or vulnerability assessment works at the local level. Considering the role of different sub-index in calculating the final risk value is a relevant exercise for the definition of the best adaptation measures that could be implemented for reducing the risk of coastal hot-spots.

Future improvements of the methodology can be obtained by improving the number of variables and defining more accurate geo-referenced standardized databases validated at the local level. The involvement of an expert panel to assign weights to the variables of CRI-MED can also improve the accuracy of the methodology.

Key remarks

From a methodological standpoint the main strengths of the CRI-MED index methodology used in this study are the following:

- The index is based on the theoretical framework defined by WGII in AR5 (IPCC, 2014);
- The methodology is based on a multiple coastal hazards approach;
- Risk as a product of forcing, vulnerability and exposure, allows to identify the real impacts of climate change on coastal areas. An approach based on vulnerability, which does not take into account the intensity of the forcing, will not necessary highlight if an highly vulnerable coastal area is even at risk;
- The selected variables, which allow to build the sub-indices of CRI-MED, can be easily measured based on available regional databases

free of charge. This aspect makes the tool particularly useful in countries with limited data availability;

- The use of ARCGIS allows, through simple operations, to transfer the values calculated for each sub-index in forcing, vulnerability and exposure maps and the overlaying of these maps to build the regional risk map;
- The regional risk map allows to make comparisons among Mediterranean coastal zones based on relative risk values;
- The method allows a scientifically sound identification of the coastal hot-spot defined as coastal zones presenting extremely high risk values.

The CRI-MED has been applied to eleven countries, namely: Morocco, Algeria, Tunisia, Libya, Egypt, Palestine, Syria, Albania, Montenegro, Bosnia and Herzegovina and Croatia. Hot-spots have been identified in Morocco (3), Algeria (5), Libya (6), Egypt (7), Palestine (1), and Syria (6).

The main lesson emerged from the regional risk assessment is that hot-spots are also areas of extremely high vulnerability. But at the same time, not all areas presenting extremely high vulnerability can be considered hot-spots, as the values of forcing and exposure for these cells range from extremely low to moderate.

Finally, given its relative ease of use, the proposed risk assessment method has a great potential to be chosen by stakeholders and decision-makers as a powerful support tool to consider and integrate climate change-related issues in planning for sustainable adaptation and ICZM strategies on their national coastal territory.

Local Risk Assessment: Implementation of the Multi-scale Coastal Risk Index in Morocco (CRI-LS)

In this section

Section 3 presents the methodology used for the Local Risk Assessment and the implementation of the Multi-Scale Coastal Risk Index at the local scale (CRI-LS) in the case study of Tetouan, Morocco.

Introduction to the Coastal Risk Index for the local scale (CRI-LS)

An Index-based method is one of the most commonly used and straightforward methods to assess coastal vulnerability and risk to climate driven impacts. The Index provides a simple numerical basis for ranking sections of coastline in terms of their potential for change that can be used by managers to identify regions where risks may be relatively high. The Index results can be displayed on maps (e.g. risk maps) to highlight regions where the climate drivers that contribute to coastal changes may have the greatest potential to contribute to these changes. According to IPCC AR5, risk can be defined as "The potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain (IPCC, 2014). Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur".

Risk generated from particular coastal hazards can be considered at various scales. Since adaptation and integrated coastal zone management are undertaken by organizations operating at various spatial scales, indices must address coastal risk at an appropriate scale (McLaughlin and Cooper, 2010). The regional-scale approach introduced with CRI-MED should enable international organization such as UNEP/MAP to define a broad picture of the coastal risk at the Mediterranean level and also to compare different levels of risk among Mediterranean countries. The risk assessment at national-scale level is addressed to countries for their prioritization of national adaptation strategies and programmes.

The practical response to coastal hazards is, however, most commonly implemented at the local level (McLaughlin and Cooper, 2010).

At each scale of management there are different considerations and different types of data. There is no 'one size fits all' index of coastal risk that can be applied at all scales. The components that contribute to the index calculation, the data availability and type, and the utility of an index approach vary with scale. For this work we propose a Multi Scale Coastal Risk Index (MS-CRI), based on a common methodological and theoretical framework, with one application at a regional level and a local level.

In the following sub-sections, we present the application of a Multi-scale Coastal Risk Index for the risk assessment of the Tetouan coastal zone in Morocco through the Coastal Risk Index for local spatial scale, called CRI-LS. According to the regional risk assessment carried out with CRI-MED presented in the Section 2, the area of Tetouan has been identified as a climate hot-spot.

Methodological framework for the CRI-LS

The multi-scale coastal risk index proposed for this work aims to investigate the implications of spatial scale in depicting coastal risk, and it refers to the work of McLaughlin and Cooper (2010). In this work, therefore, we assess the potential for a multi scale coastal risk index based on a common methodological and theoretical framework that has applicability at the regional (CRI-MED) and at the local level (CRI-LS).

The main differences between the two scales, are definition of the coastal unit, based on the coastal hazard zone and the choice of variables used to describe the three sub-indexes. Moreover higher resolution is required at the local compared to the regional scale. In fact, in order to obtain more detailed information to plan appropriate strategies, we introduced several more variables for the sub-indexes of vulnerability and exposure, while the variables of the forcing sub-index are the same of the CRI-MED.

The development of the CRI-LS method is based on the four following steps:

- ***Definition of coastal unit for the local analysis***
- ***Definition of the variables associated to each factor (sub-index) and the scores of the variables classes***
- ***Aggregation of variables, calculation of the three sub-indices and of the final index***
- ***Construction of risk maps.***

Definition of the coastal unit for the local scale

The ideal area of application of the CRI at the Local Scale is the coastal area where the hazards occur. In this sense we need now to explore the extension of the effects of the hazard on coastal areas concerned. It must be understood what the geographical and geomorphological boundaries of the effects of each hazard are. The coastal hazard zones must be defined through a technical assessment conducted by a coastal hazard specialist, and even if they cannot say precisely what will happen in the future they must highlight areas potentially threatened by coastal hazards (Ramsay, 2012). In this work, referring to Satta (2014), the coastal hazard zone is defined as the coastal zone affected by the occurrence of the hazard effect, which has the potential to cause damage to, or loss of, natural ecosystems, buildings, and infrastructure. With regards to this point, Article 8 of the ICZM protocol specifically provides the definition of setback areas for the Mediterranean coastal regions, considered as the landward limit of the buffer zone behind the coastline, beyond which is defined the acceptable level of risk produced by coastal hazard (Satta, 2014). This buffer zone is the area where restrictions on constructions and other activities should be applied with respect to a specific need for planning and management of the coastal zone (Satta, 2014). Taking into consideration that the main hazards acting as forcing in the Mediterranean are erosion and flooding (Hemmings et al., 2013,) this means that the overall hazard zone results from the overlaying of the erosion hazard zone and the flooding hazard zone. As presented by Niazi (2007) the maximum retreat of the coast of Tetouan, in the worst SLR scenario for 2100, amounted to 77m. We can therefore affirm that the erosion hazard zone of the study area is included in the 300m side of the cell considered as a reference unit for this work. To identify the hazard zone for flooding we need to consider the maximum water level (the inundation level) at the shoreline resulting from extreme wave conditions (100-years Return period) and extreme SLR. In Snoussi (2008) the inundation levels for the coastal area of Tetouan have been assessed using empirical approaches. In particular, the inundation level is derived applying the equation proposed by Hoozemans et al. (1993):

$$Dft = MHW + St + Wf + Pf$$

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

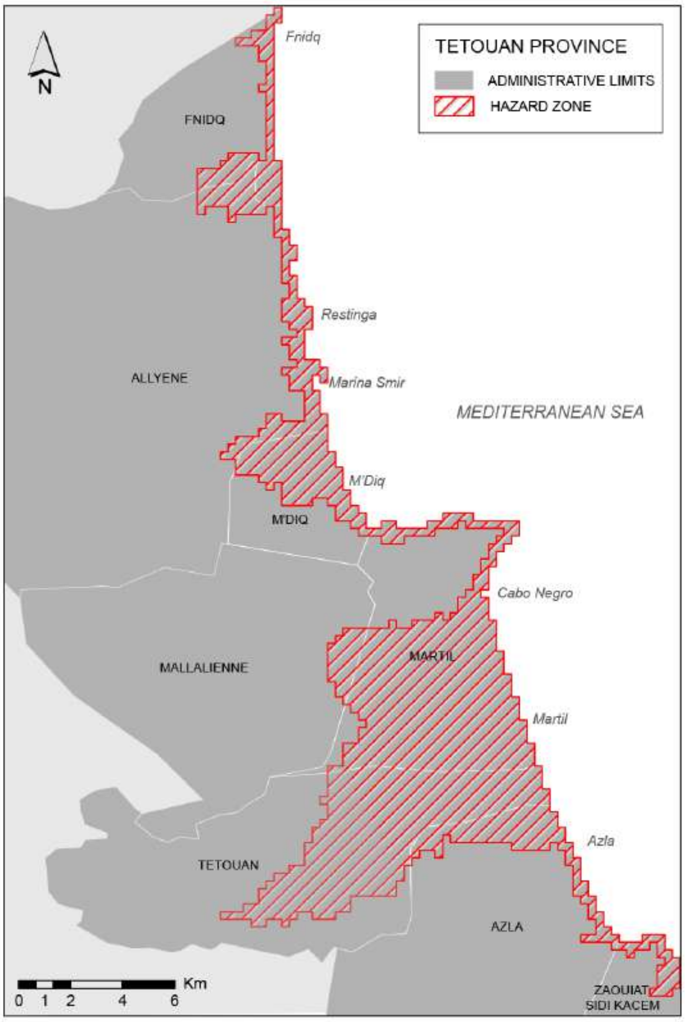
The maximum inundation levels was calculated by Snoussi et al. (2008) using a mean value of 0.96 m for MHW, a storm wave height of 6.20 m with a return period of 1 per 100 years, and a high estimate 0.86 m for sea-level rise. These values were related to the hydrographic zero, which was 0.70 m below the general datum in Morocco. The value of the maximum inundation level calculated by Snoussi et al. (2008) is 7.64. The likely range of sea level rise in 2100 for the highest climate change scenario is 52 to 98 centimetres (20 to 38 inches). However, Anders Levermann, lead author of the chapter on sea level for the IPCC's Fifth Assessment Report notes that should sectors of the marine-based ice sheets of Antarctic collapse, sea level could rise by an additional several tenths of a meter during the XXI century.[23] Thus, applying the precautionary principle, as the upper value for SLR in 2100, we consider 1.5 meters. If we integrate the value of 1.5 m in the equation we obtain a value of 8 m. To define the hazard zone for flooding we propose a theoretical approximation. We consider the area under the value Dft considering a flood that spreads inward without friction. The mass of water is pushed inwards until the height of 8m. This approximation is very precautionary since it is evident that the friction of the ground would reduce the penetration force of the flood that would stop long before reaching the altitude of 8m. This theoretical approximation is needed to identify the area

[23] http://e360.yale.edu/content/feature.msp?id=2698 (accessed March 25, 2015)

in which the flooding could theoretically develop and on which we apply the risk index.

This area, which represents the "coastal hazard zone", is represented in Figure 11.

Figure 11. Coastal Hazard zone for the region of Tetouan, Morocco



Definition of CRI-LS variables

As above mentioned, one of the main characteristics of the CRI-LS is the number of variables that describe the local context and in particular the vulnerability of hazard zones. It could be argued that the more numerous the variables describing the sub-indexes then the more correct will be the resulting values of the coastal risk index. This is not true in an absolute sense, since many of the variables used can be highly correlated, and then you could simplify the total number of the variables themselves (McLaughlin and Cooper, 2010).

For the calculation of the CRI-LS, as we did for the CRI-MED, we need to choose variables describing the threes sub-indexes: coastal forcing, coastal vulnerability and coastal exposure. We choose 6 variables for the Forcing sub-index, 11 variables for the Vulnerability Sub-Index and 2 variables for the Exposure Sub-index for a total of 19 variables. We refer to the classes proposed by Satta (2014) with some adjustments for the local scale of Tetouan.

In this work, following Satta (2014), a scale of 1–5 is chosen, with 5 contributing most strongly to the overall risk and 1 contributing least. The 1–5 scale that was used for every variable standardizes the scoring system and enables variables measured in different units to be combined mathematically (McLaughlin and Cooper, 2010). Variables and related rankings are presented in Table 11.

Table 11. Variables choice and ranking for the CRI-LS index

COASTAL FORCING SUB-INDEX							
Variable	**Description**	**Unit**	**Score**				
			1	**2**	**3**	**4**	**5**
Sea Level Rise	The simplest way to define the SLR forcing variable is to determine how much the level of the sea increases in one year, with a value expressed in cm/year (Satta, 2014). Satellite altimetry data provides accurate measures from the regional to the local level for a limited time range. In the case of the Mediterranean this range is 20 years	mm/y	SLR ≤ 1	1< SLR ≤ 1,6	1,6 < SLR ≤ 2,4	2,4 < SLR ≤ 3,2	SLR > 3,2
Storms (SWH)	We consider the Significant Wave Height as a good proxy by which to measure storm intensity and impacts on the coast (Satta, 2014). We define the Storms forcing variable as the average number of detected SWH above 95 percentile / year (SWHx95p). This variable represents the number of events exceeding the long term (e.g. return period Tr = 100 years) 95 percentile of daily SWH (Satta, 2014).	cm	SWH ≤ 50	50 < SWH ≤ 150	150 < SWH ≤250	250 < SWH ≤ 350	SWH > 350
Mean Annual Max Daily Precipitation	The average annual maximum daily precipitation total is the highest amount of precipitation received during the year, averaged over 30 year. Daily rainfall categories	mm/d	≤ 16	16 < MDP ≤ 32	32 < MDP ≤ 64	64 < MDP≤ 128	> 128

	adapted from Alpert et al. (2002)						
Droughts	The variable represents the Mediterranean regions that experienced significantly drier winters during 1971-2010 than the comparison period of 1902-2010. Low (and negative) values indicate a scarce sediment supply to beaches contributing to erosion.	mm	DRO >36	12 < DRO ≤ 36	-12 < DRO ≤ 12	-36 < DRO ≤ -12	DRO < -36
Population growth	Population growth (annual %) is the exponential rate of growth of midyear population from year t-1 to t, expressed as a percentage.	%	PGR ≤ 0,1%	0,1% < PGR ≤ 0,5%	0,5% < PGR ≤ 1%	1% < PGR ≤ 2%	PGR >2%
Tourist arrivals	International inbound tourists are the number of tourists who travel to a country other than that in which they have their usual residencet	%	TOUR ≤ 0 %	0 % < TOUR ≤ 1%	1% < TOUR ≤ 5%	5% < TOUR ≤ 10%	TOUR > 10%
COASTAL VULNERABILITY - SUB-INDEX							
Variable	**Description**	**Unit**	**Score**				
			1	**2**	**3**	**4**	**5**
Landform	This parameter indicates the erodibility of the coastal zone in terms of landform. Scores are ranked according to the relative resistance of a given landform to erosion.		Hard Rock shores	Soft Rock shores	River deltas, estuaries and cobble beaches	Sandy shores backed by bedrock or artificial structures and	Sandy shores and water plains

						artificial frontage	
Coastal slope	Is the slope of the It is used to determine the relative risk of the shoreline retreat. Low sloping coastal regions should retreat faster.		> 0,1	0,06 - 0,1	0,034 – 0,05	0.021 - 0,033	0,020 – 0,010
Land roughness	Roughness represents the resistance to surface flow exerted by the land surface and is measured with the so called Manning's coefficient.	Manning coefficient (n) associated to LC	Urban areas	Forest and Water bodies	Shrub land, grasslands, Sparse vegetation	Agriculture	Bare areas
Historical Shoreline change	Percentage of eroded coast / Sediment budget	%	> 30% in accretion	10% - 30% in accretion		10% - 30% erosion	> 30% erosion
Elevation	It represents the surface of selected coastal unit (pixel) within a specific class of elevation Xi (e.g. 0.15m_Xi _ 0.3 m)	m	5,26 - 8	3,6 - 5,25	2,76 - 3,5	1 - 2,75	el < 1
Distance from the shoreline	Susceptibility decreases getting far from the shoreline. Scores are inspired by Ozyurt but adapted to a more real progression of the risk according to the inland penetration of the flooding.	m	D > 4500	2101 - 4500	901 - 2100	300 - 900	D < 300
River flow regulation	It represents the impact of any dam infrastructure on rivers in term of flow regulation that is negative in terms of new sediment contribution (Oziurt, 2007)		no dams		Dams only in the minor tributaries		Dams in the largest tributary

Ecosystems health	A coastal ecosystem is healthy when it functions as a continuum of natural buffer systems protecting against storm surges, flooding and other coastal hazards. Ecosystems include coral reefs, sea grass beds, sand dunes, coastal wetlands and coastal forests.	Ecological status by expert judgement	No detectable change. All reference species present	Slight signs of disturbance	Moderate distortions with loss of 50% of species	Major distortions	Severe distortions with loss of all species
Education level	Percentage of population whose level is equal at least to the level 3 of the international standard classification of education (ISCED)	%	> 60	44 – 60	28 – 43	10 - 27	< 10
Age of population	The oldest are expected to be the least able to absorb and respond to changes.	% of population over 65	< 3	3 – 8,5	8,6 – 15	16 – 20	> 20
Coastal protection structures	Artificial protection to erosion.	%	> 50	31 - 50	21 - 30	5 - 20	< 5

COASTAL EXPOSURE SUB-INDEX

Variable	**Description**	**Unit**	**Score**				
			1	**2**	**3**	**4**	**5**
Land Cover	The LC map from 2010 is a global land cover map at 300m spatial resolution.		Bare areas	Shrub land, grasslands, Sparse vegetation	Forest and Water bodies	Agriculture	Urban areas
Population density	The population density is derived by dividing the population count grids by the land area grid. It represents population per Km2	% of pop / Km2	PDE < 25	26 - 50	51- 100	101 - 250	PDE > 250

CRI-LS index calculation

Even at the local scale, the numerical values for the three sub-indices (coastal forcing, coastal vulnerability, and coastal exposure) are weighted according to value judgements and multiplied through the ARCGIS raster calculator and the results are then categorized by creating classes as a percentage of the maximum and minimum scores possible.

The formulas for deriving the three sub-indexes are shown below.

$$\text{Coastal Forcing (CF) sub-index} = \{[(W_{SLR} * S_{SLR} + W_{SWH} * S_{SWH} + W_{MDP} * S_{MDP} + W_{DRO} * S_{DRO} + W_{PGR} * S_{PGR} + W_{TOUR} * S_{TOUR}) - 1] / 4\}$$

Where: S_{SLR} = score of SLR variable; S_{SWH} = score of SWH variable; S_{MDP} = score of Mean Annual Maximum Daily Precipitation; S_{DRO} = Score of DRO variable; S_{POP} = score of POP variable; S_{TOUR} = score of TOUR variable; W_{SLR} = weight of SLR variable; W_{SWH} = weight of SWH variable; W_{MDP} = weight of Mean Annual Maximum Daily Precipitation; W_{DRO} = weight of DRO variable; W_{PGR} = weight of PGR variable; W_{TOUR} = weight of TOUR variable

$$\text{Coastal Vulnerability (CV) sub-index} = \{[(W_{LF} * S_{LF} + W_{SLO} * S_{SLO} + W_{HSC} * S_{HSC} + W_{ELE} * S_{ELE} + W_{D} * S_{D} + W_{RFR} * S_{RFR} + W_{EH} * S_{EH} + W_{EDU} * S_{EDU} + W_{P65} * S_{P65} + W_{CPS} * S_{CPS}) - 1] / 4\}$$

Where: S_{LF} = score of Landform variable; S_{SLO} = Score of Slope variable; S_{HSC} = score of Historical Shoreline changes; S_{ELE} = score of Elevation variable; S_{D} = Score of Distance from the shoreline; S_{RFR} = Score of River Flow Regulation; S_{EH} = Ecosystem Health; S_{P65} = score of P65 variable; S_{EDU} = score of EDU variable; S_{CPS} = Score of Coastal Protection Structures; W_{LF} = weight of Landform variable; W_{SLO} = Weight of Slope variable; W_{HSC} = weight of Historical Shoreline changes; W_{ELE} = weight of Elevation variable; W_D = Weight of Distance from the shoreline; W_{RFR} = Weight of River Flow Regulation; W_{EH} = Ecosystem Health; W_{P65} = weight of P65 variable; W_{EDU} = weight of EDU variable; W_{CPS} = Weight of Coastal Protection Structures

$$\text{Coastal Exposure (CE) sub-index} = \{(W_{LC} * S_{LC} + W_{PDE} * S_{PDE}) / 5\}$$

Where: S_{LC} = score of Land cover variable; S_{PDE} = score of PDE variable; W_{LC} = weight of LC variable; W_{PDE} = weight of PDE variable.

The final CRI-LS index is computed through by multiplying the three sub-index values, as shown in the formula below:

$$\text{CRI-MED} = \text{CV sub-index x CF sub-index x CE sub-index.}$$

Study area description

Tetouan coast stretches over 40 km along the northwestern Mediterranean coast of Morocco, between Fnideq village in the north and Ras Mazari headland in the south. The shoreline is composed of two beaches separated by the Cabo Negro promontory (see Figure 12 below). Tetouan coast is one of the Mediterranean coastal areas that have been the most rapidly and densely urbanized in Morocco.

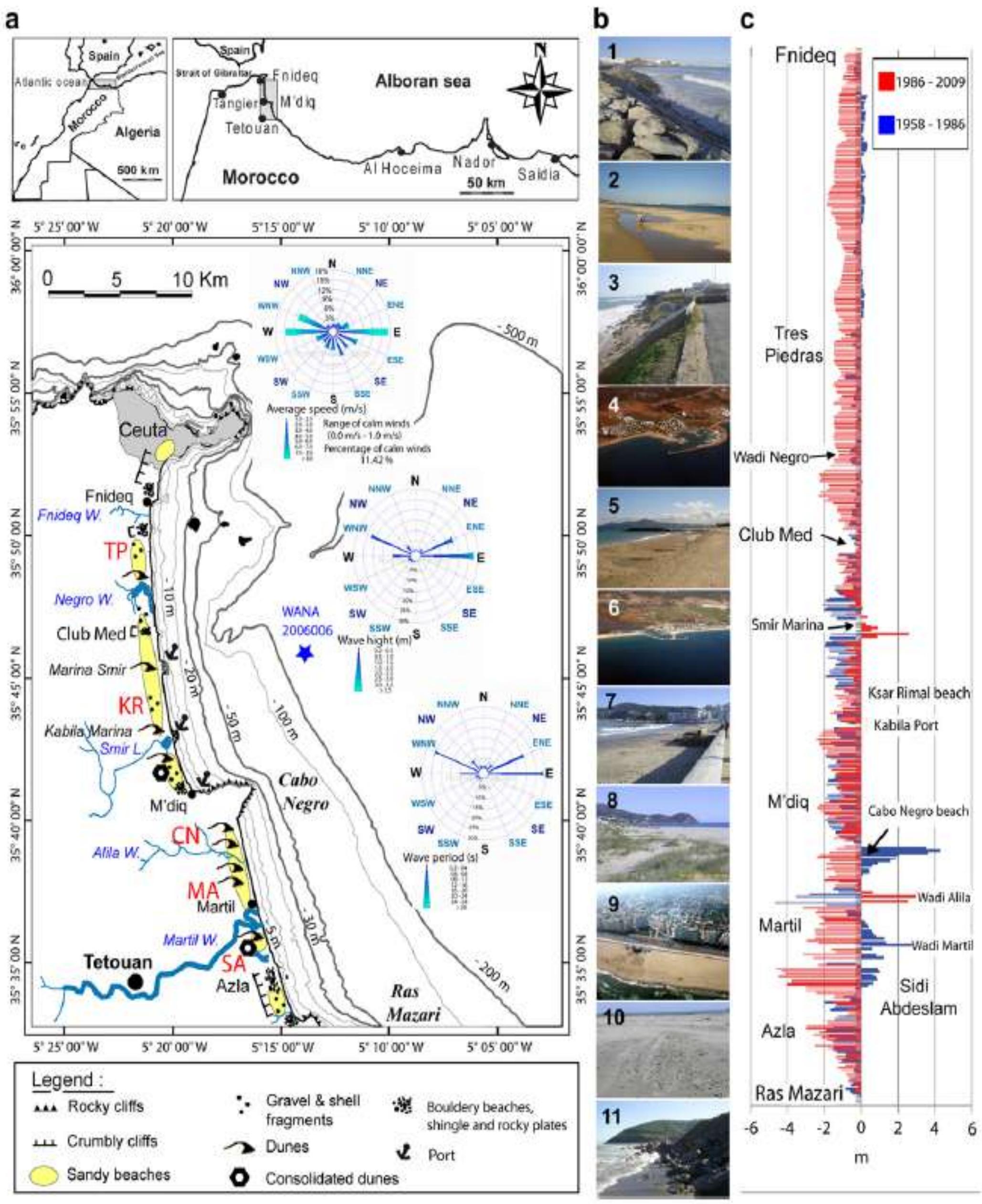
Unfortunately, development has been expanded without any integrated vision or long-term planning. Highly developed sections of the coast coupled with the high-energy, swell-dominated nature of the near shore makes it increasingly vulnerable to coastal erosion, storm surges and extreme weather events (El Mrini, 2011).

Being a dynamic and resilient system, the coastline responded with adjustments where and when possible, but more often with a retreat when the sand failure was not able to adjust. As a consequence, the coastline is now so heavily 'artificial zed' that it is no longer possible for the beaches and the adjacent wetlands to migrate upwards or adapt to any new conditions imposed by the future sea-level rise.

Tetouan coastline has already been the subject of many studies, especially regarding its past and recent evolution in response to natural and anthropogenic forcing (Niazi, 2007). All studies revealed a more or less significant erosion trend of the shoreline since the last decades. The drivers of change are multiple, including damming, sand mining, linear urbanization and construction of ports and marinas. Over 95% of the coastal dunes have been destroyed by housing and tourism infrastructure. The short-term sedimentary evolution of the shoreline have been analyzed by El Mrini (2011), using digital elevation models obtained from three successive surveys conducted during the stormy period of February and March 2008.

Results showed that seasonal beach changes are not very significant; the most important variations were recorded after storms. The type and mobility of beaches are function of their curvature and distance from headlands, exposure to waves, grain size and sediment supply. Morphological changes are faster and more excessive in reflective beaches located north of the Cabo Negro promontory; moreover, these beaches have a greater tendency for erosion. Historical shoreline positions for Tetouan coast, captured from multi-date aerial photographs for the period 1958 to 2003 (Niazi, 2007; Snoussi et al., 2008) and 1958-2007 (El Mrini, 2011) showed an erosive trend of the shoreline. Eroded beaches represent 70% of the coastline, while the accretion areas account for only 14%. The overall coastline retreat is on average 80 meters in the north and 45 meters in the south coast. Average erosion rates are -1.8 m / year in the northern coast (between M'diq and Fnideq) and -1.0 m/yr in the southern sector (Cabo Ngro to Azla) (Niazi, 2007; Snoussi et al., 2008).

Figure 12. Geomorphologic features (a), photographs (b), and coastal line evolution (c) of Tetouan, Morocco (Source: El Mrini et al., 2012)



Location map with main geomorphological features of the study area and monitored beaches: TP . Tres Piedras beach, KR . Ksar Rimal beach, CN. Cabo Negro beach, MA . Martil beach and SA . Sidi Abdeslam beach.

Photographs showing different areas of Tetouan's coast: 1. Sea wall at Fnideq, 2. Tres Piedras beach after storm (31/12/2005), 3. Outcrop of rocks at ClubMedbeach, 4. SmirMarina port, 5. Ksar Rimal beach after storm(31/12/2005), 6. Kabila Marina port, 7.M'diq beach, 8.Dunes at CaboNegro beach and the headland behind, 9. Martil beach, 10. Wind deflation at Sidi Abdeslam beach (05/03/2006), 11. Cliff erosion and Ras Mazari headland behind. Coastline evolution between 1958 and 2009.

Building the CRI Local Scale spatial index

The CRI-LS like the CRI-MED combines multiple variable layers, representing different aspects of risk, in sub-indexes (vulnerability, forcing and exposure) layers, in such a way that risk "hot-spots" as well as areas of relatively lower risk emerge from the integration of the layers (USAID, 2014). The first relevant difference between the CRI-MED and the CRI-LS is that the second uses a greater number of variables for the vulnerability sub-index with the aim to better approximate the real context. The second difference regards the area of application. For the regional level of CRI-MED we considered just the first line of 300 x 300 squared cells, while the CRI-LS index is applied directly to the hazard zone defined as the area where risk can potentially occur. The values for each variable, represented by a layer, are normalized to a consistent ordinal or unit-less scale from lowest to highest. The scaled layers are then averaged or added together to come up with a score referring to its contribution to coastal risk. The variables, the sources and the weights for the three sub-indexes are presented below.

Coastal Forcing Sub-Index

The variables selected to describe the Coastal Forcing sub-index for the CRI Local Scale (Table 12) are basically the same that we've used for the CRI-MED. The only difference is the addition of the variable "Mean Annual Daily Maximum Precipitation" because, as opposed to the regional scale, data at local scale for the region of Tetouan are available. The total number of variables for the Coastal Forcing sub-index is 6. It's interesting to note that the data we used for measuring SLR and SWH for the Moroccan coast in the CRI-MED, retrieved from regional models, are consistent with the data available from local measurements. (El Mrini, 2011). The values used to build the variables of not forcing climate, population growth and tourism, are extracted from the local values available for the regions of Morocco.

Table 12. Variables for the CRI-LS Coastal Forcing sub-index

n	Variable	Territorial unit / image resolution	Data sources	Data format	Weight (%)
1	Sea Level Rise	Medit. Sea / 25km resolution	AVISO database	georeferenced image (tiff)	30%
2	Storms (SWH)	According to the iso-values of the SWH trends map (within 500m offshore from the shoreline)	El Mrini (2011) & Niazi (2007)	Table	25%
3	Mean Annual Maximum Daily Precipitation		http://www.water.gov.ma/	Table	10%
4	Droughts	Medit. countries	NOAA website	image (.jpg)	5%
5	Population growth	Nation	http://www.hcp.ma/	Table	20%
6	Tourism arrivals	Nation	http://www.tourisme.gov.ma/	Table	10%

Regarding the allocation of weights, SLR and SWH represent the variables that contribute the most to forcing even locally. We assume, instead, that the variable "Mean Annual Maximum Daily Precipitation" contributes to forcing more than the variable "droughts", respectively 10% and 5%. In the presence of extreme daily precipitation the effects of coastal flooding are more devastating.

Coastal Vulnerability Sub-Index

The main difference between CRI-MED and CRI-LS, as anticipated in previous sections, concerns the number of variables describing the sub-index coastal vulnerability. The CRI-LS has the specific aim of describing the risk levels of the coastal area covered by the study, as specified in section 2.2, is represented by the hazard zones. Vulnerability is the predisposition of the area to be affected by the impacts of climate change and particularly their effects on natural hazards such as erosion and flooding. The Hazard Zone was defined as the area under the altitude of between 8 m and the coastline. The main hazards acting on the coast are erosion and flooding. The first exerts its effect only on the coastline and up to a maximum distance of 77 m, in the worst-case SLR scenario for 2100 (Niazi, 2007). This allows us to conclude that only the first line of cells of 300mx300m side is interested by erosion. As we've seen for the CRI-MED, the variable, which contributes the most to describe the impacts of erosion, is landform. The question changes substantially regarding the extent of flooding. To define the extent of the impacts of flooding, which coincides with the hazard zones, we made a purely theoretical premise. We forecast that the flooding penetrated into the interior without finding any obstacle stopping at an altitude equivalent to extreme inundation level, i.e. 8m. In a real context, these conditions are not realistic because there are several factors that will stop the advance and therefore reduce the risk. In real conditions, the variables that most influence the penetration of flooding are the distance from the shoreline and land roughness. Even without introducing a mathematical model of flooding inland penetration, it is still possible through these variables to approximate the effects of flooding. Particularly relevant in this sense is the distance from the shoreline. This variable allows us to estimate how the impact of coastal flooding reduces in proportion to the increase of the distance. Land roughness represents the resistance to surface flow exerted by the land surface and is measured with the Manning's coefficient. Manning's roughness can be estimated with land cover classes using a GIS for large-scale applications (Kalyanapu et al, 2009). The 11 variables used to build the Coastal Vulnerability sub-index are presented in Table 13. A weight is associated to each variable. We attribute the weight of 15% to Landform and Distance from the shoreline variables as they contribute the most respectively to erosion and to flooding.

Table 13. Variables for the CRI-LS Coastal Vulnerability sub-index

n	Variable	Territorial unit / image resolution	Data sources	Data format	Weight (%)
1	Landform	Local	Niazi, 2007	map image	15%
2	Coastal slope	Local	Niazi, 2007	map image	10%
3	Land roughness	Local	Chow, 2009	map image	10%
4	Historical Shoreline change	Local	Niazi, 2007; El Mrini, 2011	table/graph	5%
5	Elevation	90m	GIS DEM	georeferenced image	10%
6	Distance from the shoreline	Local	GIS		15%
7	River flow regulation	Local	www.water.gov.ma		5%
8	Ecosystems health	Local	Bibliography & expert judgement	table	10%
9	Education level	Nation	www.hcp.ma	table	5%
10	Age of population	Nation	www.hcp.ma	table	5%
11	Coastal protection structures	Local	Expert evaluation	table	10%

Coastal Exposure Sub-Index

The variables selected for the sub-index Exposure of the CRI-LS are the same as for CRI-MED: land cover and population density (Table 14). Regarding the variable Land Cover we used the same database that for CRI-MED with a resolution of 300m. For the population density, we defined the data in more detail by placing the values for each coastal municipality of the region of Tetouan. We keep the same weights we have used for the CRI-MED.

Table 14. Variables for the CRI-LS Coastal Exposure sub-index

n	Variable	Territorial unit / image resolution	Data sources	Data format	Weight (%)
1	Land Cover	Medit. Countries / 300m resolution	ESA map	Georeferenced image (tiff)	70%
2	Population density (Inhabitants / Km2)	Nation	http://www.hcp.ma/	Table	30%

Applying the CRI Local Scale spatial index

Main results

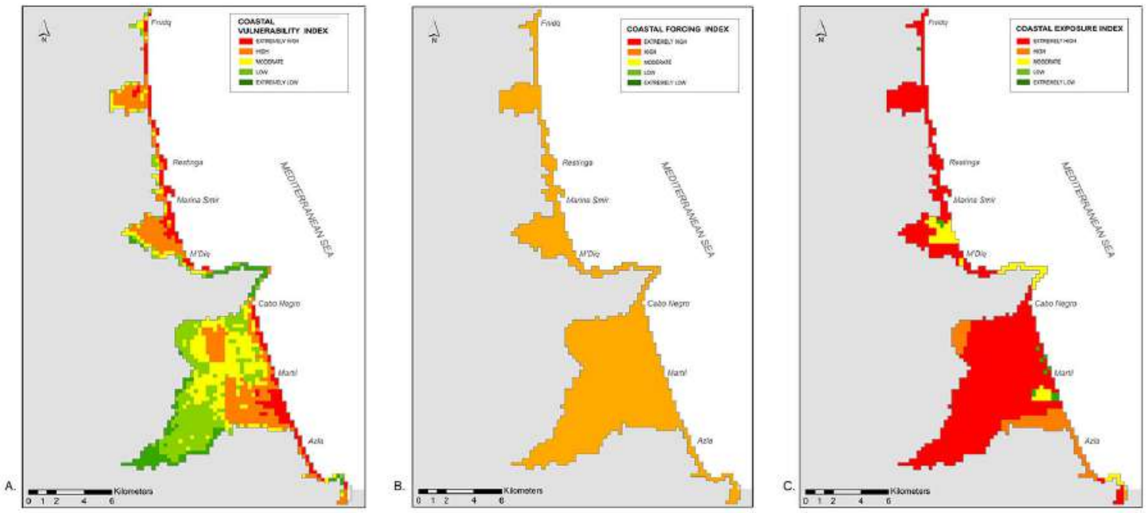
The application of the CRI-LS to the coastal area of Tetouan led to a ranking of the relative risk of the area defined for the study, the hazard zone, in relation to potential coastal hazards generated and/or exacerbated by climate and non-climate forcing.

The goal of the CRI-LS method is to provide a useful tool for coastal planning at a local level.

The maps produced by CRI-LS allow identifying levels of risk not only for the shoreline but also for the internal areas potentially affected by flooding.

The local risk map allows visualizing the qualitative ranking of risk; all variable data layers were assigned a risk score and a weight. The CRI-LS equation, with weighted variables, is applied to each 300m x 300m cell of the coastal hazard zones for a total of 1.284 cells. The maps obtained for the three sub-indexes are shown in Figure 13.

Figure 13 Forcing (a), Vulnerability (b), and Exposure (c) maps of Tetouan, Morocco



Forcing

The value of the forcing is constant throughout the area and is equal to 0,7125. The local scale defined for the case of Tetouan, does not allow to distinguish the values for the climate forcing (SLR and SWH) and non climate (Population Growth and Tourism Development) as for the regional scale.

Vulnerability

To calculate the vulnerability values associated with each cell, we made some simplifications to take into account the differentiated effects of some variables on erosion and flooding. For example the variable "landform" acts only on erosion while it has a neutral effect on flooding. For this reason the scores of "landform" (from 1 to 5 according to the geomorphology), have been assigned to all the cells within line of 300 m, while for the other cells of the "hazard areas" we've assigned a constant value equal to 3 because it does not affect the impacts of coastal flooding.

Other variables that represent the susceptibility component of vulnerability (elevation, slope, distance from the shoreline) decrease with increasing distance from the coastline. The variable "land roughness" varies according to the land cover and plays a key role in the vulnerability of the cells compared to the impacts of flooding and then the preparation of the same cells at risk.

Exposure

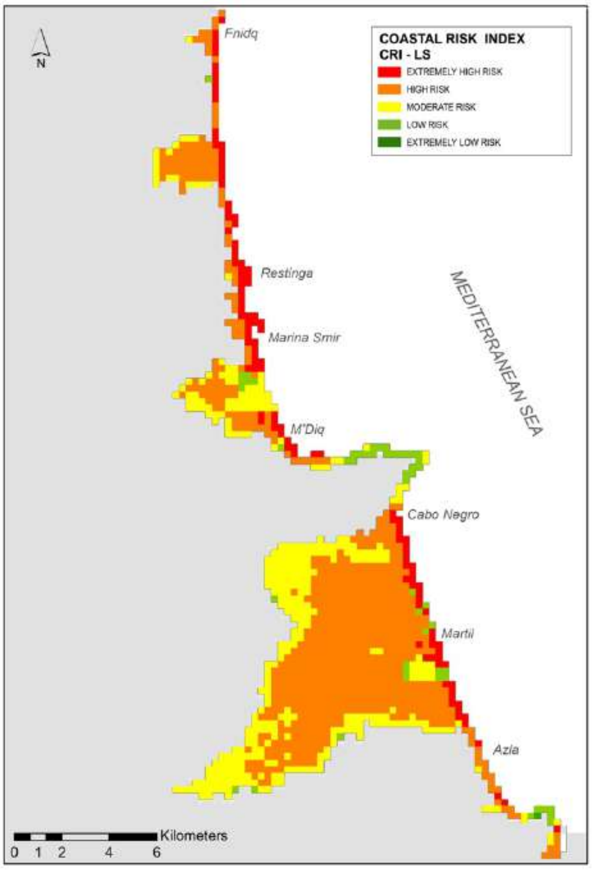
Most of the cells included in the "hazard zone", are characterized by urban land use which is associated to a high population density (e.g. Fnidq = 1879,3 hab/km^2, Tetouan = 4121,6 hab/km^2, MARTIL = 1164,5 hab/km^2)

In some cases we have values equal to 0,58; south of the Marina Smir and south of Martil, where there are two areas with land use "Forest and Water Bodies" (in yellow). Apart from a few cells characterized by land cover "bare areas", and low-density housing (shown in green), the whole area shows values of exposure from high to extremely high.

The CRI-LS scores are obtained by multiplying the scores obtained by three sub-indices. The final risk rankings are dimensionless numbers that judge the relative degree of risk of coastal zones to each analysed coastal hazard, in relation to qualitative risk classes (i.e. extremely high, high, medium, low, extremely low). **Contrary to the index CRI-MED, higher risk values imply high risk in absolute terms and the proposed CRI-LS methodology allows ranking the risk at the local scale of the studied area**.

The scores for each pixel are calculated using the function “Raster calculator”, which allows performing calculations on the basis of existing pixel values and obtaining the results written into a new raster layer. The risk scores obtained applying Raster Calculator to the coastal area of the Tetouan region range from 0.19 to 0.60. To classify the scores obtained for each cell, we use a manual grouping method with ranges of 0.1. The result is presented in Figure 14.

Figure 14. Coastal zone risk map of Tetouan, Morocco



The Local Risk map obtained illustrates that the cells showing extremely high risk values (colored in red) are concentrated in the first line. This is due to the superposition of maximum risk than the impacts of that from those of the flooding. **The area of maximum extension of the risk from erosion even in the worst scenario SLR 2100 is less than 100m**. In order to better appreciate the differences, it would be necessary to introduce a land cover with a higher resolution (e.g. 10m).

Discussion of results

One of most evident outcomes of the risk map, with respect to that of vulnerability, is that in the risk map even at distances of over 5km inland from the coast the risk remains high.

This is particularly true for the following flood plains considered from north to south (Niazi, 2007):

- **Restinga Plain,** located between Fnidq and M'diq is the closest coastal plains of Tetouan covering an area of 10 km. It is traversed by the river Negro, with wetlands and salt marshes and the shore is as a sandy beach of the same name.
- **Smir plain**, located north of M'diq. It is an area of 12 km2 and its slope is generally lower 1.5%.
- **Martil Alila Plain**, is the largest in the region with an area of 86 km. Its topography is as a basin whose bottom does not exceed 2 m. Characterized by low elevation and low drainage, the major part of its area is exposed to floods.

The high levels of risk that characterize these areas, distant from the coastline, are due on one hand to the topography of the flood plains and on the other hand to the high values of exposure. In this regard, it is possible to conclude that the forcing factor at the local scale is less relevant.

It has to be noted that in the local application of the coastal risk assessment method, the geographic scale corresponds to the resolution unit of the measures used for the climatic variables. Which implies that in practice at the local level it is not possible to detect meaningful variations in terms of climatic variables. The same reasoning can be applied to non-climatic variables. In fact, available data to measure population and tourism trends are available only at supra-local level (regional or national).

List of local hot-spots identified in Tetouan, Morocco:

- ***Restinga Plain***
- ***Smir plain***
- ***Martil Alila Plain***

Conclusions

Limitations and future improvements

The variables chosen for the calculation of the three sub-indexes, depend on data availability at the local level. In the case of Tetouan thanks to the support of the University of Rabat (Prof. Snoussi) it has been possible to gather all the data necessary for the application of CRI-LS.

It would be theoretically possible to have more information taking into account the climatic variables such as population growth and tourism development that can vary locally in a very significant way. In this case, by assigning larger weights to the non-climatic variables, it would be possible to put in evidence the differences, even substantial, between the different municipalities of the same region.

Particularly relevant in the analysis of the local risk is the contribution of the Exposure factor, which can be further refined with a higher definition Land Cover (e.g. 10m x 10m). Tetouan is highly urbanized with a high-density housing that makes the area extremely exposed to coastal risk. The map of vulnerability at the local level, takes into account as many as 11 variables with the goal to describe the susceptibility and resilience to the impacts of the area of erosion and flooding.

The application of the CRI-LS identifies the areas at risk within the hazard zone defined with the maximum inundation level under the worst SLR Scenario in 2011. In this regard, the CRI-LS can support coastal managers in developing adaptation measures and in allocating resources to respond to coastal erosion and coastal flooding to those areas at highest risk.

Comparison of the two indexes: regional and local scale

The clear advantage of the multi-scale index is the choice of the perspective/detail balance. Users can make the tradeoff appropriate to their needs by choosing the most suitable index scale for the scale of management.

We were able to assimilate data at different spatial scales and adapt them to portray coastal risk in a common format at two different scales.

This study indicates that spatial scale is also an important consideration in the development of coastal vulnerability indices. No single scale is suitable for all needs. Different scales tend to reflect different priorities, and the influence of a given variable will increase or decrease as scale changes. Multi-scaled indices like those presented for this work, have the capacity to be used in assisting coastal policy makers at different scales and scope of application. Nevertheless, according to McLaughlin and Cooper (2010), major differences exist between the regional and the local level. For the application of CRI-MED detail is sacrificed in order to gain perspective on the risk of the whole Mediterranean coastline and on the opposite, for CRI-LS the level of detail is high but the overall perspective is low (McLaughlin and Cooper, 2010).

Ultimately, it is up to the coastal manager or policy maker to determine the most appropriate scale or scales of index to apply, depending on whether the policy is a national-, regional- or local-level one, and to also be acutely aware of the potential limitations of the scale or scales of the index they are using.

In the ideal world, indices would be based on local-level information that is aggregated and simplified as larger scales are considered. However, this is not often feasible in terms of data availability, storage and processing, and in terms of the time scale needed to undertake such risk assessment.

The main characteristics of the two indexes CRI-MED and CRI-LS are illustrated in the table below.

Table 15. Comparison of the CRI-MED and CRI-LS methods

CRI-MED	CRI-LS
Objectives	
Analyze the levels of relative risk of Mediterranean coastal regions and to identify coastal hot-spots.	Define the range of risk for a more effective planning of adaptation and ICZM.
Spatial Unit	
The analysis is carried out on a single dimension that is the linear segment of the coast of 300m thickness equal to the resolution of land cover.	The analysis is carried out on the "hazard zone". The hazard zone is defined taking into account the value Dft (maximum inundation level) in a 2100 scenario. The method introduces the dimension perpendicular to the coastline and approaches the problem in terms of area and not of the segment.
Climate Scenario	
The CRI-MED is based on values of current climate forcing and assesses the current impact in relative terms between the different coastal regions of the Mediterranean.	The CRI-LS takes account directly of climate change scenarios to 2100. The CRI-MED does not take into account these scenarios as its main objective is to define the level of relative risk between the coastal areas of the Mediterranean regardless of the potential scenarios of change in 2100.
Application	
CRI-MED allows to evaluate the Mediterranean regions at risk on which to intervene and to prioritize the adaptation strategies. CRI-MED allows to obtain useful results even apart from the prediction of climate models on future scenarios.	The utility of the CRI-LS is in coastal planning and in particular in the allocation of resources for coastal defenses. The CRI-LS can be used for the definition of the setback zone within the framework of the ICZM Protocol. With higher Land Use resolution, the application of CRI-LS makes possible to identify infrastructure in potentially highly risk areas.

Conclusions

In this section

This sections presents the key findings and recommendations to be taken up by the Mediterranean coastal stakeholders community.

Key findings

Climate change risk management, while a new field, is not without precedent in the Mediterranean and around the world. This report focuses on evaluating and applying good practice methodologies for coastal risk and vulnerability assessment in order to lay the groundwork for the informed development of climate change adaptation and ICZM strategies in the Mediterranean, with emphasis on how to make decisions despite scarce resources, limited local data and information about the future.

Based on the present research, some key findings are highlighted below as a basis for ongoing discussion with Mediterranean stakeholders and decision-makers:

- As an assumption, the use of visualization techniques (e.g. risk maps) are acknowledged to provide a means to improve this knowledge transfer procedure and promote wider community inclusion within the decision-making process.
- Based on an overview of existing relevant methodologies and tools, a Multi-scale Coastal Vulnerability Index method (McLaughlin and Cooper, 2010) was selected as the point of departure for a regional and local risk assessment in the Mediterranean, because of its numerous advantages, including the consideration of physical as well

as socio- economic variables, the presence of three separated sub-indices representing vulnerability, its non expensive and easy calculation process, the possibility to integrate the concept of risk as proposed by IPCC AR5, the possibility to obtain vulnerability maps as an outcome, and the potential for application at various scales.

- One advantage of this approach is that separate maps for each risk component (vulnerability, forcing, exposure) allows supporting decision-makers to analyse adaptation options. The relatively high degree of transparency of these methods represents a clear advantage. On the other side, the method must face important challenges concerning how to weight the variables, since the weighting will ultimately affect the visualization and interpretation of results (USAID, 2014). In this technical report the data and methods used in spatial risk assessment are clearly documented, and information on uncertainties and assumptions are included as part of the risk mapping.
- The Multi-scale Coastal Vulnerability Index was reworked and developed into a Multi-scale Coastal Risk Index by integrating the concept of risk developed in the Fifth Assessment Report of IPCC (2014) where it is described as a result of the interaction of vulnerability, exposure and climate forcing. The Multi-scale Coastal Risk Index and risk mapping can identify vulnerable populations and locations at risk and provide a tool for coastal adaptation decisions. The methodology integrates exposure and vulnerability mapping to inform choices about which populations, infrastructure, and areas to prioritize for action.
- The application of the CRI-MED, Multi-scale Coastal Risk Index methodology to the eleven Mediterranean countries selected for the project ClimVar & ICZM, led to a ranking of the relative risk of each coastal region in relation to potential coastal hazards (coastal erosion,

coastal flooding and saltwater intrusion) generated and/or exacerbated by climate and non-climate forcing.

- The hot-spot threshold was set in a way to highlight only areas that appear *exceptionally* at risk according to the statistical distribution of cells, where areas at high risk are located next to areas that are also at high risk.
- The application of the CRI-MED methodology at the Mediterranean scale resulted in the identification the following coastal hot-spots: Morocco (Tetouan, Nador and Saidia), Algeria (Ain El Bia, Tenes, Zeralda, Tassoust and Annaba), Libya (Tripoli, Misrata, Benghazi, Darianah, Tocra and Ad Dirsiyah), Egypt (Sidi Barrani, Marsa Matrouth, Alexandria, Baltim, Ras El Bar, Port Said, Al Arish), Palestine (the Northern shore of Gaza Strip), Syria (the shore from Al Hamidiyah to Tartus, the shore from Tartus to Marqueh, Baniyas, the shore from Jable to Latakia, Om Al Toyour and Ummetli).
- The risk maps resulting from the implementation of the CRI-MED represent the visualization and prioritization of risk in the coastal zones of the Mediterranean. The risk assessment approach highlights some substantial differences with the traditional vulnerability assessment methods. In fact, the identified Mediterranean hot-spots can also be considered areas of extremely high vulnerability. But at the same time, not all areas presenting extremely high vulnerability can be considered hot-spots, as the values of forcing and exposure for these areas range from extremely low to moderate.
- The application of the CRI-LS, Multi-scale Coastal Risk Index for the local risk assessment in the Tetouan coastal zone in Morocco led to the identification of three coastal hot-spots located in flood plains (Restinga Plain, Smir plain, Martil Alila Plain).

- While the Forcing factor at the local scale is less relevant, in the analysis of the local risk what counts the most is the contribution of the Exposure factor.
- The Multi-scale Coastal Risk Index methodology, proposed for the regional and local coastal risk assessment respectively through the application of the CRI-MED and CRI-LS, allows a scientifically sound detection of the coastal hot-spots defined as coastal zones presenting extremely high risk values. As such, CRI-MED and CRI-LS represent relatively simple and non-expensive tools to support decision-makers in the spatial identification of the coastal areas characterized by different vulnerability and exposure levels and in the definition of adaptation options.

Recommendations for future research

Database of risk assessment methods and tools for the use of decision makers. Further developments of the exercise that allowed to create an initial database of relevant methods and tools for risk and vulnerability assessment in the Mediterranean are possible. A web-based searchable tool can be developed based on the early overview contained in this report, allowing to represent the many guidelines, frameworks, methodologies and practical resources available to aid policy makers integrate climate variability and climate change into their typical decision making processes and activities. Specific guidance can also be provided on how climate vulnerability, risk, adaptation, monitoring and evaluation and awareness raising can be integrated into each activity/decision type. The Caribbean Community Climate Change Centre and Acclimatise used a similar approach to identify the most appropriate tools and techniques relevant in a Caribbean context when developing the Caribbean Climate Online Risk and Adaptation Tool (CCORAL).

Regional assessment in the Mediterranean through CRI-MED. Upgrading of the methodology contained in the present report can be obtained by improving the number of variables and defining more accurate geo-referenced standardized databases validated at the regional/local level. The involvement of an expert panel to assign weights to the variables of CRI-MED can also improve the accuracy of the methodology. Also, providing non-experts with the ability to alter the weights can be valuable. The tool can be used interactively to enable politicians, decision-makers and the wider public to see how changes in weighting affect the index. Furthermore, it is essential to develop regional models to assess storms variability and trends that can offer data for the index.

Local assessment through CRI-LS. Improvements in the analysis of risk at local scale can be obtained by further refining measurement of the Exposure factor, with a higher definition Land Cover (e.g. 10m x 10m).

Hot-spots definition. The regional assessment allowed to identify a number of coastal hot-spots in a relatively simple and cheap way through the implementation of the CRI-MED. However, the current project did not foresee a detailed investigation of all the resulting hot-spots, but it was limited to one case study to validate the methodology at the local scale. Local data availability was considered an issue at this stage. Additional resources should be dedicated to this effort in order to refine the analysis of hotspots.

Stakeholders' involvement. In the context of this assessment, ClimVar & ICZM Project partners agreed that stakeholders (focal points) could be engaged in providing feedback to the research. However, engaging them in a full exploration of adaptation options at the local level was deemed to be beyond the available time and resources within the current project. Such activity could be done in a next phase of the research to complement local risk assessment exercises (e.g. with country workshops and more direct interactions).

Next steps

The analysis contained in this report is part of an ongoing, evolving discussion with Mediterranean stakeholders and experts, a discussion aimed at exploring how decision-support methods and tools can be best utilized to evaluate climate-related risks faced by local coastal realities in the Mediterranean. This document is intended to provide a useful point for discussion within ongoing institutional processes in the Mediterranean under the auspices of UNEP/MAP, including the development and adoption of the Regional Climate Change Adaptation Framework in the Mediterranean and the revision of the Mediterranean Strategy on Sustainable Development.

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Annexes

Annex 1: Good practices of adaptation from OURCOAST database

Soft action: Training coastal managers from cross-border regions – Spain (Total budget 43,121 EUR in 2005, 38,032 EUR in 2006, and 40,000 EUR in 2007). The Advanced Seminars of the Azahar Programme focused on three major Mediterranean sub-regions: Maghreb, Middle East and south-eastern Europe. The seminars were oriented to technical coastal experts and managers, representatives from the different administrations of the Azahar Mediterranean countries. The goal of these seminars was to improve the south-eastern Mediterranean coastal management by transferring to their coastal managers some Spanish and European experiences, knowledge, tools, techniques and technologies for the development and implementation of Mediterranean ICZM. Training and capacity building was provided on various topics, including integrated characterization of the coastal areas; tools and technologies for ICZM; techniques for stakeholders stock-taking and public participation processes; implementation of coastal plans and programmes; risk (natural and human) assessment and coastal processes.

Green/grey action: Dune nourishment to protect the coastal lagoon from washover, Sicily – Italy (Total budget 831,180 EUR, supported through EU LIFE scheme). The main goal was to restore the ecological balance of the coastal ecosystem and the dune habitats that had been eroded and at the same time to increase bird fauna biodiversity. The protection and restoration of dunes focused on three main actions that are in line with ICZM: the creation of a wooden fence along the dune's perimeter to avoid disturbance by users; the construction of three walkways ensuring the possibility for tourists to access the beach; the installation of wind-breaking barriers to favour sandy sediment deposition, leaving to nature the task to rebuild the missing tract of the dune. The work ended in 2005. The activities successfully contributed to stopping the degradation and improving the ecological condition of the coastal dunes habitat.

Soft/green action: A strategy for sustainable tourism – Slovenia (Total budget n.a.). This project aimed at elaborating a joint vision, objectives, strategy and a regional programme for sustainable development of tourism covering the territory of eight municipalities of the Slovenian Coast - Kras region spanning over 1,500 km^2. The ultimate goal was to preserve regional authenticity and at the same time improve quality and provide long-term international competitiveness for the destination, raising local incomes. This project was designed as a component of a Regional Development Programme for the Slovenian coastal region South Primorska. Between 2004 and 2006, several measures for the realisation of the strategy were undertaken, including: improving tourism infrastructure; the development and marketing of new tourist products and services; the promotion of high-quality tourism and reduction of environmental impacts; the creation of partnerships for sustainable development among national tourism actors.

Grey/green action: Improved water resource management in areas with acute water shortage – Malta (Total budget n.a.). This project aimed to improve water supply in the Maltese archipelago as part of an integrated water resource management strategy and reduce the investment cost of coastal dependent, sea-water desalination plants. As an exercise of a proper strategic management at a corporate level, an innovative economic leakage intervention model has been developed. This model is designed to act as a tactical planning tool focused towards daily resource utilization and tactical planning decisions with one objective: guiding the practitioner towards reaching the long-range goals and targets of the Water Service Corporation as quickly and economically as possible. Additionally, an Integrated Water

Management System has been developed. This is essentially an information system that utilizes a data model and a geographical information system which is used primarily as a mid to high-level decision-making and decision-assisting tool. With limited options to either decrease demand or increase supply without large-scale, expensive solutions, the problem of water leakage has been tackled. A process has been set up whereby water lost to leakage has been reduced by 50% eliminating the need for expensive desalination plants along the coast.

Annex 2: Database of method and tools for climate risk and vulnerability assessment

DESCRIPTION					EVALUATION (compliance with evaluation criteria, expert judgment)						
Method	Developer	Category	Description	Objectives	Format, accessibility and ease of use	Relevance to the Mediterranean coastal areas	Based on ICZM approach	Relevance for building adaptation options	Economic/ costing information	Multiscale approach	Tot score
BTELSS	Reyes et al., 2000	Methods based on dynamic computer models	The output data are in the form of maps of land change, (habitat switching), flooded and eroded areas, plant productivity, salinity, open water circulation, and sediment transport. Data requirements: elevation, bathymetry, DEM, air temperature, wind speed & direction, precipitation, river discharge, sediment load, wetland land cover, regional salinity, plant growth & mortality rates, flooding.	To investigate and predict the environmental factors affecting wetland habitat change	1	3	3	3	1	1	12
CanVis	NOAA	Visualization tools	CanVis is a visualization program used to "see" potential impacts from coastal development or sea level rise. Users can download background pictures and insert the objects (hotel, house, marina, or other objects) of their choosing.[1]	To simulate potential impacts from sea level rise for the use of coastal decision-makers	3	2	1	3	1	1	11

CCFVI	Balica et al., 2010	Index/Indicators based methods	The CCFVI system can be used as an instrument to assess which areas are most vulnerable to flood. This system helps decision-makers to control the possible damages and distinguish the precise measures for implementing before flooding (Balica and Wright, 2010). The Flood Vulnerability Index can be used in action plans to manage flooding and can improve local decision-making practices with appropriate measures to reduce vulnerability in different spatial levels (Balica et al., 2009).	To calculate flood vulnerability in certain areas.	3	2	3	3	1	2		14
Composite Vulnerability Index	Szlafsztein and Sterr, 2007	Index/Indicators based methods	This index applies the same principles of CVI and Multi-CVI indexes. It combines a number of separate variables/indicators (natural and socio-economic characteristics that contribute to coastal vulnerability) and once selected, indicators are aggregated according to an appropriate set of weights (ETC-CCA, 2011). It can be easily combined with GIS maps.	To assess ecological and socioeconomic vulnerability.	3	2	3	3	1	1		13
COSMO	Taal, 2011	Visualization tools	COSMO is a computer GIS-based model that support coastal managers to evaluate adaptation strategies under different scenarios, included climate change (Taal, 2011).	Aims to support coastal managers to explore the effects of coastal management measures to respond to climate change impacts.	3	1	2	2	1			9

CVI	Gornitz, 1991;	Index/Indicators based methods	CVI tables and maps are the output data; CVI is classified in groups using percentage limits (ranked into low, high, very high). Input parameters are: Geomorphology, Coastal slope, Relative sea-level rise, Shoreline erosion/accretion, Mean tidal range, mean wave height.	To map the relative vulnerability of the coast to future sea-level rise.	3	3	1	1	1	2	11
CVI (SLR)	Özyurt, 2007	Index/Indicators based methods	It defines 5 CVI sub-indices, each one related to a specific sea- level rise impact. These are integrated in a final CVI (SRL) index. It can be integrated to GIS to produce maps. The input parameters are: 12 physical (e.g. geomorphology, sediment budget and water depth at downstream) and 7 human influence (e.g. reduction of sediment supply and land use pattern) parameters.	To assess vulnerability of physical system, socio-economic (i.e. land use) and ecological systems	3	3	2	3	1	2	14
DELFT3D MODELLING SUITE	Deltares	Methods based on dynamic computer models	Output data: maps, graphs and tables regarding water levels, including ground water, water depths, velocities, currents, sediments, etc.; Delft3D provides a flexible, modeling suite, including visualization tools. Input data: meteorological, hydrological, topographic and bathymetry data, DTM, roughness, vegetation, wind, pressure, time series; land use and land use planning.	To model both natural environments like coastal, river and estuarine areas and more artificial environments like harbors, locks and reservoirs	1	3	2	1	2	1	10

DESYCO	Torresan et al., 2010	GIS Based Decision Support Tools	The model provides vulnerability maps by GIS, Hazard maps, Exposure maps, Susceptibility maps, Value maps, Vulnerability maps, Risk maps, Damage maps.	To assess socio-economic and ecological vulnerability	3	3	3	3	2	1	15
DITTY-DSS	Mocenni et al, 2009	GIS Based Decision Support Tools	The Ditty Decision Support System was developed within the EU project DITTY (Development of an Information Technology Tool for the Management of European Southern Lagoons under the influence of river-basin runoff, contract EVK3-CT-2002-00084). The model manages information from mathematical and analytical models of a lagoon ecosystem. The DSS is based on a multicriteria analysis.	To assess the influence of watershed basin runoff and the influence of shellfish farming on ecosystem equilibrium and to develop early warning systems	2	3	3	3	1	1	13
DIVA	Hinkel J., 2005	Methods based on dynamic computer models	Estimates of population flooded wetland changes, damage and adaptation costs, amount of land lost. The model requires elevation (SRTM), geomorphic and form types, coastal population, land-use, administrative boundaries, GDP	To conduct national assessment of vulnerability in small island nation; Socio-economic and ecological targets	1	3	3	3	3	1	14

EVA	Virginia Institute of Marine Science Center for Coastal Resources Management, 2008	GIS Based Decision Support Tools	EVA allows to identify areas alongshore that have demonstrated historic patterns of instability, and currently support valued natural, social, or economic resource[3]. EVA uses a 50-year planning window to project shoreline position in 50 years to inform local planners through vulnerability maps where community infrastructure, cultural resources, and habitat are potentially at risk in the future.	To identify coastal areas vulnerable to erosion and support erosion mitigation actions	2	1	3	3	1	1		11
FUND	Tol, 2006; Tol et al., 2006	Methods based on dynamic computer models	It provides rates and statistics for decision making/makers. It requires population and scenarios on emissions, climate change, sea-level rise, global warming and other impacts.	To measure economic costs and benefits	1	3	1	3	3	1		12
GVA	Deltares	Methods based on dynamic computer models	It determines the number of people at risk of flooding, loss of coastal wetlands. The model requires changes in flooding caused by storm surges.	To conduct global vulnerability assessment of all coastal countries	2	2	1	2	1	1		9
HAZUS-MH	FEMA, 2000	Methods based on dynamic computer models	Maps delineating hazard characteristics, dollar value of the study region exposure, direct economic losses, essential facility, functionality, shelter requirements and debris.	To estimate potential losses from earthquakes, hurricane winds, and floods.	1	1	3	2	3	1		11

InVEST	Natural Capital Project (Sharp et al, 2014)	Methods based on dynamic computer models	InVEST is a suite of software models used to map and value natural goods and services (including sixteen distinct InVEST models) and intends to support decision-makers to choose the best alternative management choices[4].	To map and value the goods and services from nature that sustain and fulfill human life	1	2	1	2	3	1	10
Multi-Scale - CVI	McLaughlin & Cooper, 2010	Index/Indicators based methods	It defines 3 sub-indices: coastal characteristic sub-index, coastal forcing sub-index, and socio-economic sub-index. Final CVI index. Indices can be represented in maps. Key variables are defined according to the specific application (location and scale). Variables refer to: resilience and coastal susceptibility to erosion, forcing variables contributing to wave-induced erosion socio-economic target potentially at risk	To produce indexes (and maps) representing socio-economic and ecological vulnerabilities	3	3	3	3	1	3	16
RACE	Halcrow Group Ltd, 2007	Methods based on dynamic computer models	It creates maps of coastal erosion hazard, overlaid with locations of vulnerable assets to create 'risk' maps. The data requirements are: expert judgment on the probability of defense failure and the natural erosion rate, validated by existing data, and field observations where possible	Private property, built assets and agricultural land	1	2	1	2	3	1	10
RCVI	Tibbetts 2012	Index/Indicators based methods	RCVI was developed by Tibetts in his MSc thesis to determine the biophysical vulnerability of a macro-tidal estuary in the Bay of Fundy to varying levels of storm surge and tide state. A conceptual framework was designed to illustrate the relative interrelationships between exposure conditions, biophysical state , and morphological resilience condition (Tibbetts, 2012).	To determine relative vulnerability of a macrotidal coastal environment	3	1	1	3	1	1	10

RegIS - Regional Impact Simulator	Holman et al., 2005	Methods based on dynamic computer models	It provides maps and graphs of changes in ecosystems, species' ranges and land use in response to scenarios of socio-economic and climate change. The model needs flood plain maps, flood risk area, sea defenses, elevation, land cover, coastal habitats database, existing and proposed sites for managed realignment and tidal surge data.	To assess socio-economic and ecological targets	3	1	3	3	2	1		13
RVA - Regional Vulnerability Assessment	Torresan et al., 2012	Index/Indicators based methods	Based on a system of numerical weights and scores, the RVA provides relative vulnerability maps that allow to prioritize more vulnerable areas and targets of different climate-related impacts in the examined region and to support the identification of suitable areas for human settlements, infrastructures and economic activities, providing a basis for coastal zoning and land use planning. This has been applied to the coastal area of the North Adriatic Sea (Italy).	To identify key vulnerable receptors (i.e. natural and human ecosystems) in the considered region and localize vulnerable hot spot areas, which could be considered as homogeneous geographic sites for the definition of adaptation strategies.	3	3	3	3	2	1		15
SCAPE	Dickson et al., 2005	Methods based on dynamic computer models	Is a "process-based model that determines the reshaping and retreat of shore profiles along the coast"[6]. Output data are available in the form of maps, dynamic visualization, and descriptive statistics of key parameters such as cliff toe and cliff top position.	To explore different sea-level rise and wave climate scenarios and protection choices[7]	2	1	3	3	1	1		11

Sea Level Rise and Coastal Flooding Impacts Viewer	NOAA	Visualization tools	Is an online software displaying SLR impacts on coastal communities. Through a slider bar is possible to observe impacts of sea level to coastal communities. This tool is very effective and powerful instrument to support coastal decision-makers and other stakeholders.	To assess climate change impacts like sea level rise and coastal flooding on coastal resources	3	1	1	3	1	1	10
SimCLIM	CLIMsystems Ltd	Methods based on dynamic computer models	This model creates maps of areas/habitats potentially vulnerable to inundation. Spatial and site-specific scenarios of climate and sea-level changes; time-series projections, graphical and tabular output. It needs DEM, Elevation, site specific time-series data, patterns of climate and sea-level changes from GCMs, impact models.	To assess climate change impacts and adaptation (both socio-economic and ecological targets)	2	2	3	3	3	1	14
SLAMM	Developed by Image Matters LLC and currently updated by U. S. Fish and Wildlife Service	Methods based on dynamic computer models	It provides maps of areas/habitats, land cover and elevation maps, tables and graphs, salinity model, inundation model, erosion model; 3D Open GL Visualizations predict changes in ecosystems. The input parameters are: elevation data wetland land type, elevation, slope, aspect; affecting wetlands: inundation, erosion, over wash, saturation, accretion, dikes protected areas.	To display scenarios of wetland fate and the vulnerability of the coast to sea-level rise	1	1	1	3	1	1	8
SMP	Leafe et al., 1998	Methods based on dynamic computer models	A range of information is required, including, ideally, historical shoreline change, contemporary coastal processes, coastal land use and values, and appropriate scenarios of change.	To address risks related to coastal evolution[8]	1	1	1	3	2	1	9

SoVI®	University of South Carolina, 2006	Index/Indicators based methods	The Social Vulnerability Index (SoVI®) 2006-10 measures the social vulnerability of U.S. counties to environmental hazards[9]. The data are compiled and processed by the University of South Carolina.	To assess socioeconomic components	2	1	1	2	2	1	9

Legend: 1 = Low compliance 2 = Medium compliance 3 = High compliance

[1] NOAA Coastal Services Centre, http://www.csc.noaa.gov/digitalcoast/tools/canvis (accessed November 4, 2013)

[2] UNFCC - https://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5353.php (accessed November 5, 2013)

[3] Interactive Maps - Center for Coastal Resources Management (CCRM), http://ccrm.vims.edu/gis_data_maps/interactive_maps/erosion_vulnerability/ (accessed November 4, 2013).

[4] Natural Capital Project - InVEST, http://naturalcapitalproject.org/InVEST.html (accessed November 4, 2013).

[5] UNFCCC, https://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5497.php (accessed November 5 2013)

[6] Applying Gis To Coastal Erosion And Hazards Environmental, http://www.ukessays.com/essays/environmental-sciences/applying-gis-to-coastal-erosion-and-hazards-environmental-sciences-essay.php (accessed November 4, 2013).

[7] A GIS Tool for Analysis and Interpretation of Coastal Erosion, http://nora.nerc.ac.uk/1536/1/GIS_coastaltool.pdf (accessed November 4, 2013).

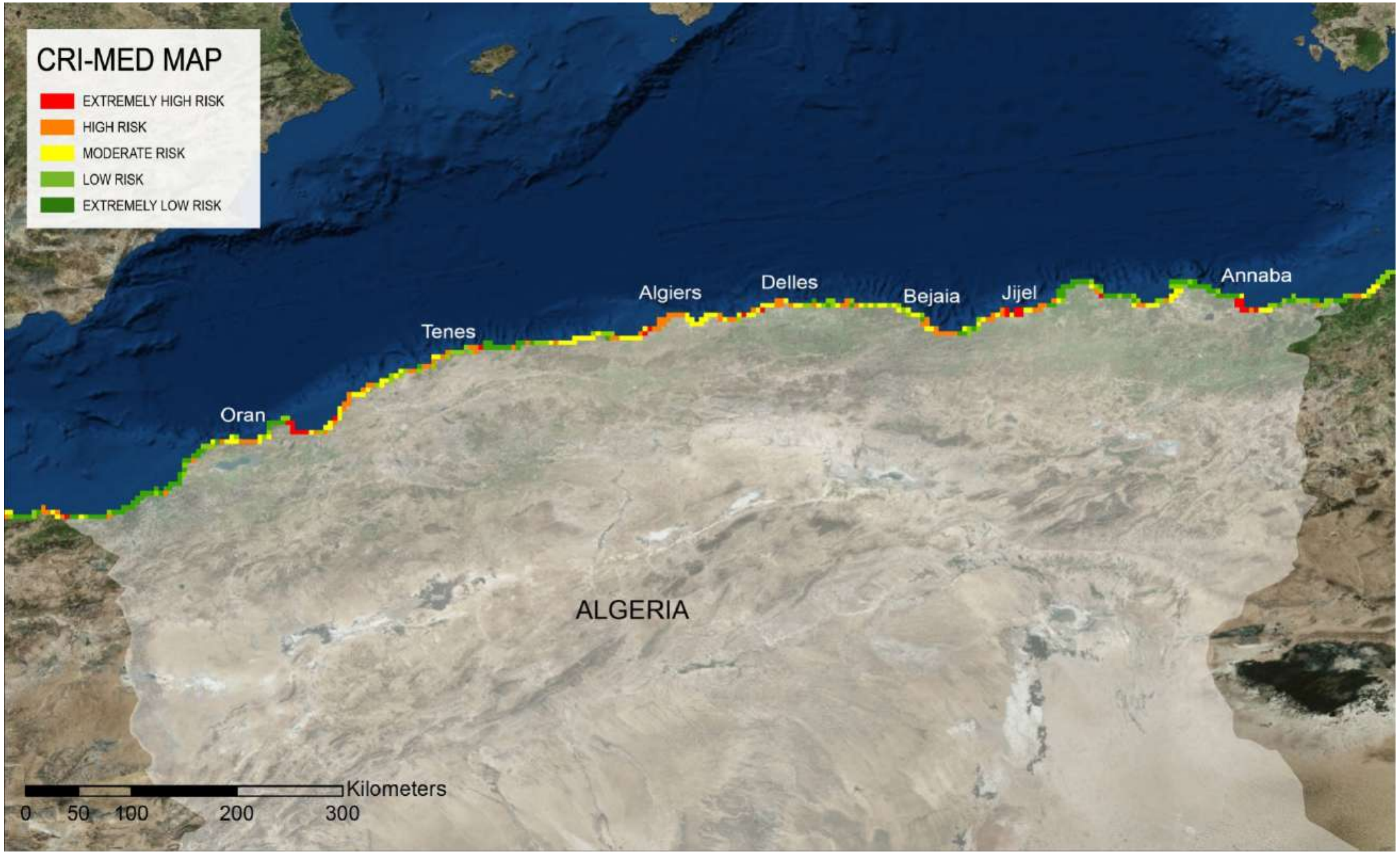
[8] apps3.suffolkcoastal.gov.uk, https://apps3.suffolkcoastal.gov.uk/committeeminutes/readdocument.asp?docid=17662_br (accessed November 5, 2013).

[9] Recovery Lessons Learned & Information Sharing | FEMA.gov, https://www.fema.gov/recovery-lessons-learned-information-sharing (accessed November 4, 2013)

Annex 3: Landform characterization of Mediterranean coastal zones

Annex 4: CRI-MED Map of Morocco

Annex 5: CRI-MED Map of Algeria

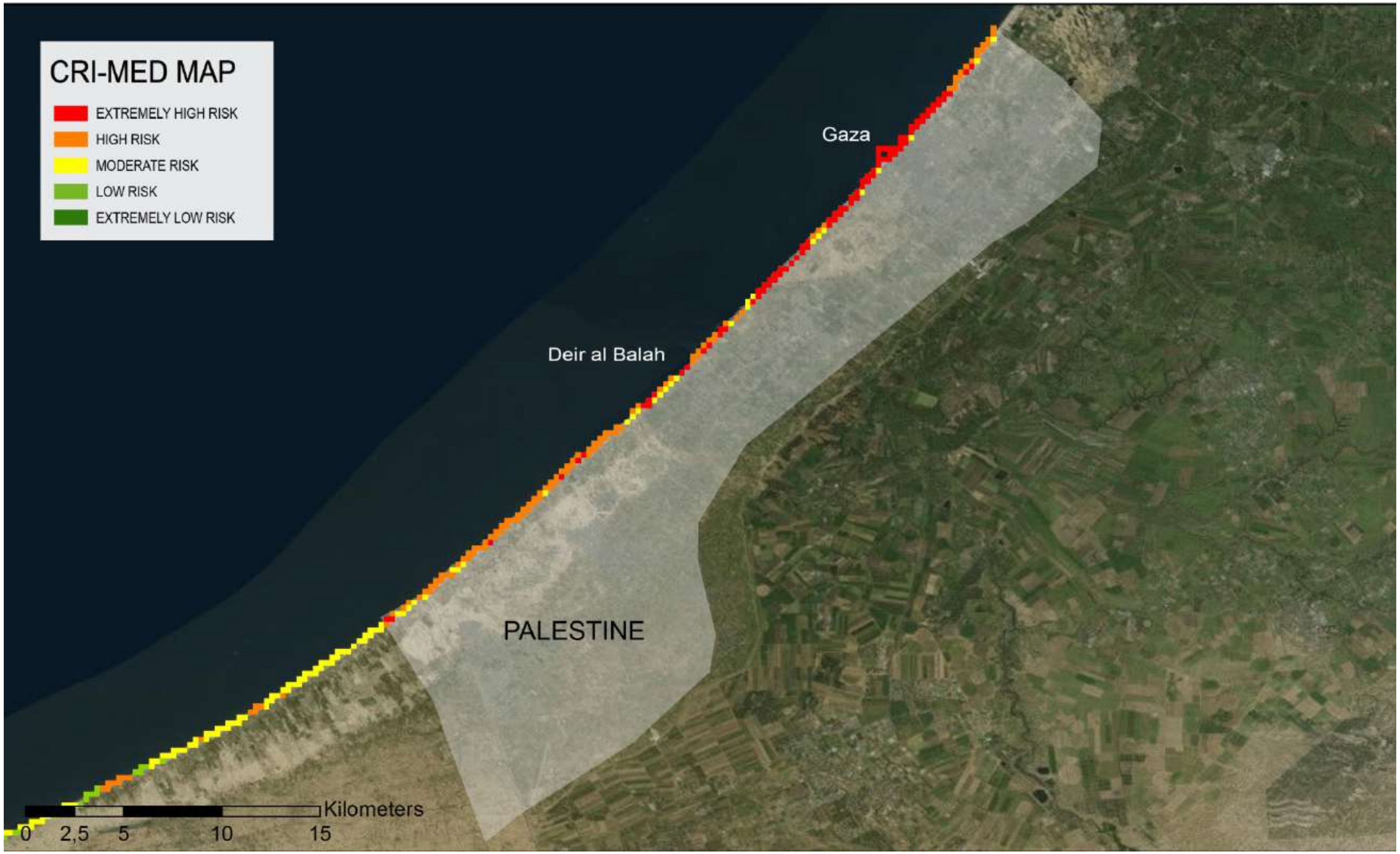


Annex 6: CRI-MED Map of Tunisia

Annex 7: CRI-MED Map of Libya

Annex 8: CRI-MED Map of Egypt

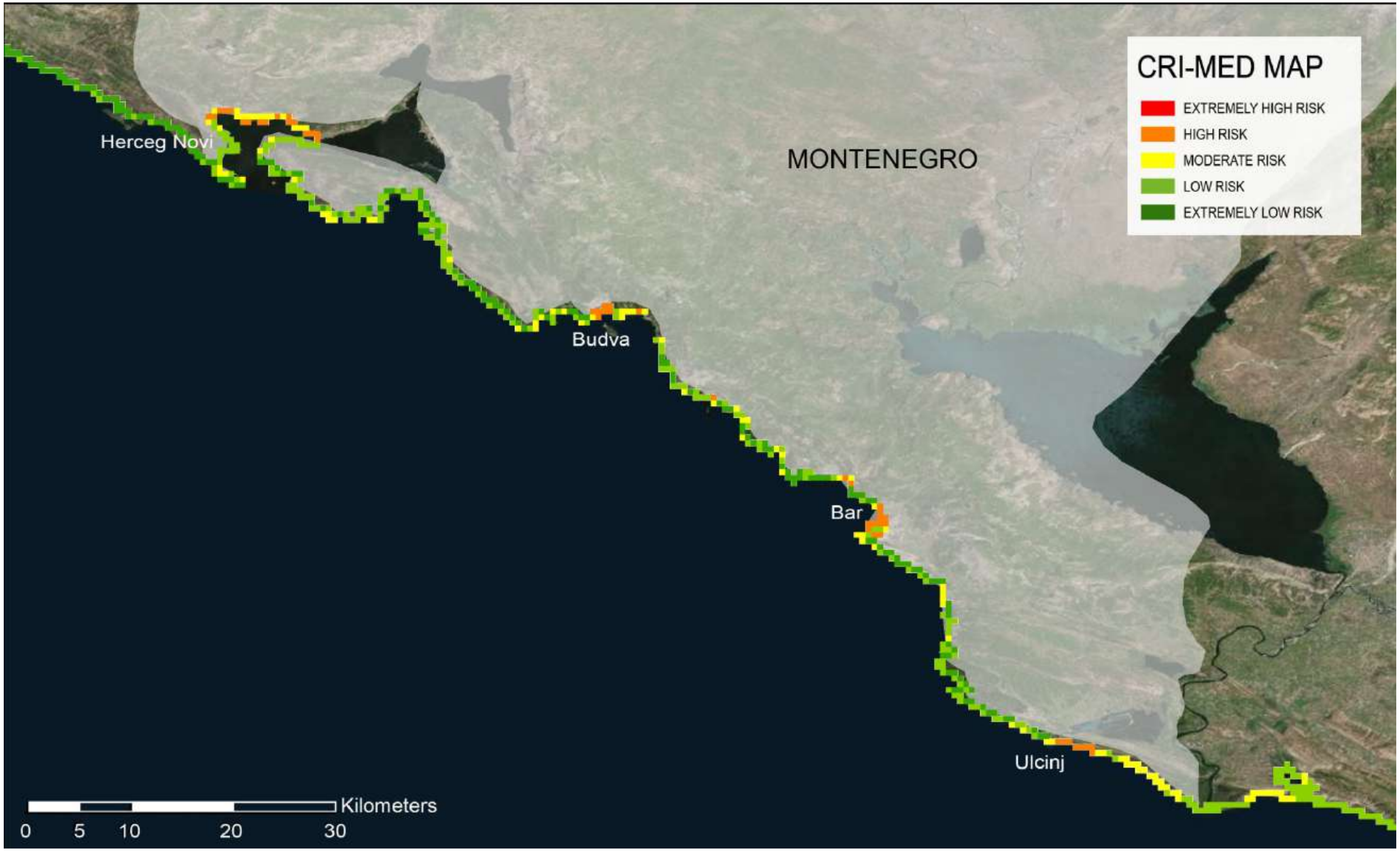
Annex 9: CRI-MED Map of Palestine



Annex 10: CRI-MED Map of Syria

Annex 11: CRI-MED Map of Croatia, Bosnia and Herzegovina

Annex 12: CRI-MED Map of Montenegro



Annex 13: CRI-MED Map of Albania

Plan Bleu, 2015.