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An Index-based method to assess vulnerabilities and risks of Mediterranean coastal zones to multiple hazards

Un Indice per la valutazione delle vulnerabilità e dei rischi generati da molteplici pericolosità sulle zone costiere del Mediterraneo

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PhD Dissertation

AN INDEX-BASED METHOD TO ASSESS VULNERABILITIES AND RISKS OF MEDITERRANEAN COASTAL ZONES TO MULTIPLE HAZARDS

By

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DECLARATION

This thesis contains no material, which has been accepted for the award of any other degree or diploma in any University. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference has been made.

Alessio Satta

December 2014

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ABSTRACT

Coastal zones are exposed to the continuous action of several factors such as wave height and direction, wind speed, tides, the rates of relative sea level change, as well as rainfall and the frequency and intensity of extreme meteorological and climate events, including storms (ETC-CCA, 2011). All these natural factors make coastal areas highly vulnerable. Sea Level Rise (SLR) and Storms generated by Climate Change could intensify the impacts generated by these factors. The contribution of WGI to the AR5 (IPCC, 2013) confirms what it was already evident from the AR4 (IPCC, 2007): SLR will intensify the impacts on coastal areas, in particular those most vulnerable in terms of reduced capacity of adaptation of the ecological and the socio-economic systems to SLR impacts. The major concern is not the global-mean SLR, but the relative sea level change observed at the local level, which includes regional sea level variations and vertical movements of the land (ETC-CCA, 2011). Recent SLR projections suggest "*remarkable changes in the climate of the Mediterranean region might occur already in the next few decades*" (Gualdi *et al.*, 2013) resulting to an expected near-surface temperature of about 2°C in the 2021–2050 period with respect to the 1961–1990 mean.

Mediterranean coasts are already included among the hotspots of vulnerability in coastal zones for the acceleration of SLR (Nicholls *et al.*, 2007a). The coastal population of the Mediterranean throughout history has adapted to natural changes and fluctuations in sea level due to any eustatic, glacio-hydroisostatic and tectonic factors. The coastal zones have a crucial importance for the Mediterranean countries as they represent a significant part of the economic activities of the states of the Mediterranean. When economic activities are developed simultaneously along a narrow coastal strip, different priorities emerge that tend to cause conflicts that require planning and integrated management efforts. The possible effects of climate change on coasts could exacerbate disputes on the use of areas and resources – these types of disputes are already common in Mediterranean coastal zones.

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. The 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. The definition of setback areas considers 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 prevention of natural hazards. The increased risks of natural hazards generated by SLR and Storms and the growing concentration of people and activities on the coastal zone requires updated information and a better understanding on coastal zones vulnerability and exposure at the local scale. Even if extreme events often cannot be predicted, adaptation measures can be planned to reduce the potential risks and to cope with uncertainties. Scientific sound operational methods are needed to assess coastal vulnerability risks to climate and non-climate drivers and to understand the interaction of climate change with socio-economic and environmental systems is of increasing importance for coastal policy makers in the Mediterranean. 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, etc. The use of visualization techniques (e.g. risk maps) provides the means to improve this knowledge transfer procedure and promote wider community inclusion within the decision-making process (Al-Kodmany, 2001; Orland, Budthimedhee & Uusitalo, 2001). To this end, the current research aims to provide Mediterranean coastal managers with an index-based approach to make an integrated assessment of vulnerabilities and risks associated to multiple coastal hazards, as a tool for the definition of sound strategies and measures for coastal adaptation to climate and non-climate forcing within the framework of the ICZM Protocol. The index-based method developed for this research is applied to a concrete case in the western shore of Sardinia.

Keywords: Climate change, Mediterranean, ICZM, coastal risk assessment, index-based approach, Sea Level Rise, Storms, non-climate forcing, vulnerability, exposure, susceptibility, resilience, coastal erosion, coastal flooding, saltwater intrusion, coastal hazard zones.

CHAPTER 1. CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

Coastal zones are exposed to the continuous action of several factors such as wave height and direction, wind speed, water depth, sediment dynamics along the coast, the strength of tides, the rates of relative sea level change, as well as rainfall and the frequency and intensity of extreme meteorological and climate events, including storm surges (ETC-CCA, 2011). All these natural factors make coastal areas highly vulnerable. Sea Level Rise (SLR) and marine storms exacerbated by climate change could intensify the impacts generated by these factors. In particular, sea level is expected to continue rising and accelerate during this century due to the increase in the atmospheric global average surface temperature.

Mediterranean coasts are included among the hotspots of vulnerability in coastal zones for the acceleration of SLR (Nicholls *et al.*, 2007). The coastal population of the Mediterranean throughout history have adapted to natural changes and fluctuations in sea level due to any eustatic, glacio-hydroisostatic and tectonic factors. Some researchers have shown that during the past 2400 years, a relative sea-level change has occurred at up to -1.98 ± 0.23m in Sardinia and up to - 2.08 ± 0.60m since 1900 ± 100 years BP in northern Adriatic (Antonioli *et al*., 2007). The coastal zones have a crucial importance for the Mediterranean countries as they represent a significant part of the economic activities of the states of the Mediterranean. For example, clean, safe and healthy beaches help to maintain the economic lifeline of Mediterranean coastal tourism destination. Climate change could contribute significantly to beach erosion creating coastal recession because of the predicted increase of storm activity and intensity, sea level rise and the interaction of both consequences; storm activity coupled with SLR pose severe problems to coastal infrastructures. A large part of human activities takes place along the coastal areas (housing, industry, agriculture, tourism, fishing, transportation, etc.). Coastal urbanization, mainly as a result of population concentration, uncontrolled tourism development and growth of recreational activities (secondary houses), has detrimental effects on the coastal environment and landscape especially in dunes, beaches and wetlands. The increase in residences on the coast, in most of the countries of south Mediterranean but also of the north, like Greece, France, Spain and Italy, means that there is increased risk, because of both the increased hazard of coastal climate impacts, and the increased exposure in terms of the number of people potentially affected as well as in terms of investments losses (e.g. coastal erosion, changed destination attractiveness, etc.).

Besides the direct impact of coastal construction on the degradation of coastal areas' natural resilience, the impact of climate change will also worsen the situation as land erosion increases with rising sea levels. At the same time healthy dunes, beaches and wetlands are important in keeping communities (and investments) resilient to climate change because they help buffer upland areas from future storms and sea level rise (NOAA, 2010). Dunes, beaches and wetlands also provide critical habitat for a number of important plant and animal species, and preserve water quality by filtering freshwater before it reaches saltwater or brackish water.

When economic activities are developed simultaneously along a narrow coastal strip different priorities emerge that tend to cause conflicts that require planning and integrated management efforts. The possible effects of climate change on coasts could exacerbate disputes on the use of areas and resources – these types of disputes are already common in Mediterranean coastal zones. The application of sectorial management policies in coastal areas in the past has proved inadequate in the challenge of resolving the complexity of the interactions between socio-economic and environmental systems. Another weakness of sectorial policies concerns the inability of assessing the simultaneous effects of different impacts (Parson et *al.*, 2003). For this reason, in recent years we are witnessing the development of an integrated approach to the management of coastal areas with the goal of balancing the benefits of economic development along the coastal areas with the long-term conservation of its ecological, socio-cultural, and historical values.

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 levels, and more generally to all those who affect the coastal regions with their activities (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 ICZM Protocol in the framework of the Barcelona Convention established a legal framework for the Mediterranean contracting parties. The Protocol, signed in Madrid on 16 January 2009, entered into force in March 24, 2011. The Protocol aims to promote a common framework for the integrated management of the coastal areas of the Mediterranean. 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 both current and future (such as the risk of flooding by rising sea levels, erosion, etc.) in order to develop policies for the prevention of natural hazards. The Protocol arises, therefore, as a fundamental legal instrument to ensure a sustainable future of the coastal Mediterranean, through rational planning, a rational use of natural resources including water resources and reconciliation of economic development with environmental protection. It constitutes, therefore, an important precedent for the Contracting Parties of the Barcelona Convention, by providing a definition of the coastal zone and integrated management of the coastal zone by introducing aspects of governance with the aim of ensuring consistency between the public and private initiatives and between the decision-making processes at the regional, national and local level. A coastal setback zone is already in force in some Mediterranean countries where ecological considerations also played their part in providing more arguments against coastal urbanization: laws such as the "*Loi littorale*" in France voted in 1986 or the Sardinian "*Legge Salvacoste*" of 2004. In Italy the definition of a "no construction zone", represents a strong answer to coastal urbanization and also a form of adaptation to potential impacts from climate change through physical and landscape planning. Planning adaptation in coastal zones is a difficult process because of the uncertainties due to climate change projections, in particular SLR, and possible impacts. The acceleration of the impacts of global warming that have emerged since the last IPCC report (IPCC, 2014a), despite uncertainties, makes it even more difficult to design effective adaptation measures.

Mediterranean coastal zones present very high population densities that lead to high social and biogeophysical vulnerabilities as, for example; coastal infrastructures exposed to direct waves and the lack of space for these vulnerable systems to move to less vulnerable areas. The increased risks of natural hazards generated by SLR and marine storms and the growing concentration of people and activities on the coastal zone requires updated information and a better understanding on coastal zones vulnerability and exposure at the local scale. Even if extreme events often cannot be predicted, adaptation measures can be planned to reduce the potential risks and to cope with uncertainties. Notwithstanding these emerging risks, lack of robust scientific knowledge, lack of local data and local experts have led to coastal decision makers under-evaluating sea level rise as an immediate threat (Ozyurt, 2010). These uncertainties demand a high degree of flexibility to adapt to climate and non-climate driven changes and in this sense designing and implementing a robust method to assess current and future vulnerability risks to coastal hazards is a challenging issue for research (Sahin, 2011). Scientific robust methods are needed to assess coastal vulnerability risks to climate and non-climate drivers and understanding the interaction of climate change with socio-economic and environmental systems is of increasing importance for coastal policy makers in the Mediterranean.

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, etc. All these 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. 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 the means to improve this knowledge transfer procedure and promote wider community inclusion within the decision-making process (Al-Kodmany, 2001; Orland, Budthimedhee & Uusitalo, 2001).

To this end, the current research aims to provide Mediterranean coastal managers with an index-based approach to make an integrated assessment of the risks associated with multiple coastal hazards, as a tool for the definition of sound strategies and measures for coastal adaptation to climate and non climate forcing within the framework of the ICZM Protocol. The study will incorporate the use of Multicriteria Analysis, Integrated Coastal Zone Management, and Geographic Information System (GIS) modelling approaches.

1.2 Research Rationale

As confirmed by the last report of the IPCC's Working Group I (IPCC, 2013) SLR generated by the Climate Changes since "*the mid-19th century has been larger than the mean rate during the previous two millennia*" and in the period from 1901 to 2010, the global mean sea level rose by 0,19 [0,17 to 0,21] (IPCC, 2013). According to the results of the CIRCE project published in RACCM (Navarra & Tubiana, 2013) the major impacts of climate change in the Mediterranean coastal regions are produced by SLR and changes in storm frequencies and intensities. CIRCE models produce a 2012-2050 mean steric sea level rise that ranges between +6,6 cm and 11,6 cm with respect to the period of reference (Gualdi et *al.*, 2013). The main effects of SLR on coastal zones are increased coastal erosion, increased flooding, salinization of groundwater (IPCC, 2014a; IPCC, 2014b). Besides SLR other climate-related effects in coastal zones exist such as the "*change in the frequency, intensity and spatial patterns of coastal storms*" and "*changes in wave climate both regarding the average direction and intensity of the transported energy*" (ETC-CCA, 2011). Even if the confidence in model projections of future scenarios of these effect is "*rather low and is beginning to improve*" (ETC-CCA, 2011). Existing studies show a small effect of climate change on marine storms and suggest weaker marine storms in future scenarios than in the present climate (Gualdi et *al.*, 2013). The reason why coastal vulnerability assessments to climate change are mainly focused on SLR and less focused on other climate related effects is mainly due to the higher uncertainty of their models' projections on future scenarios (Nicholls et al., 2008).

Assessing the vulnerability of coastal zones, taking into account only the climate drivers, it is far too simplistic. To carry on a complete risk assessment of the coast it must be considered also the direct and indirect pressures resulting from human-induced drivers such as the population growing, economic development and related land-use changes (ETC-ACC, 2011). For these reasons, coastal vulnerability and risk assessments "*should adopt an integrated approach considering climate and non-climate-induced environmental changes, socio-economic developments and the mutual interaction among these facto*rs" (ETC-ACC, 2011). Non-climatic environmental and socio-economic changes have often been disregarded in coastal vulnerability and risk assessment scientific literature even if climate change impacts will result from the interaction between climate and non-climate forcing (Nicholls *et al*., 2008). The interaction between climate and non-climate drivers and the relation between physical and socioeconomic effects are presented in Figure 1.1. The physical effects of SLR may induce a wide variety of socio-economic effects such as, increased flood risk, loss of land and coastal habitats, and potential loss of life, damage to coastal protection works and other infrastructure, loss of tourism, loss of agriculture, loss of cultural resources, etc. (ETC-CCA, 2011).

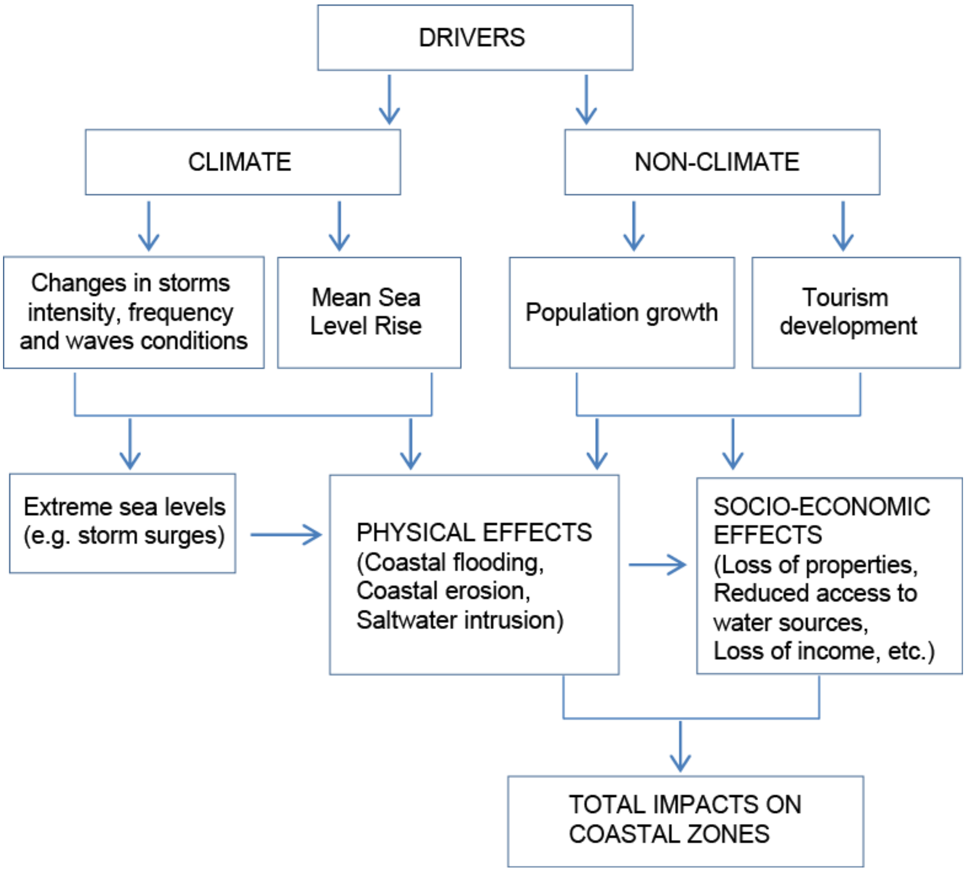


Figure 1.1 Conceptual model of Climate Change effects on coastal regions due to Sea Level Rise and storm tides. (Source: own elaboration from Sahin, 2011)

The consequences of these changes will have a direct effect on both natural systems and socio-economic aspects of coastal areas of the Mediterranean countries. In particular, the low-lying coastal areas and islands, which are particularly vulnerable to flooding, erosion and saltwater intrusion of coastal aquifers. To implement efficient adaptation measures to natural hazards and at the same time to continue to provide the same usages is not an easy goal to reach. In fact, one of the main features of the coastal areas of the Mediterranean is the superposition, in very narrow areas, of high concentrations of human activities and ecosystems rich in priority habitats. The historical weakness of research on adaptation has meant that experts have tended to communicate mainly about risks and can offer few solutions. Although this approach is important, it is often badly received by the players directly concerned. Moreover, even when describing risks, there is a need for more local modelling and information but these are often given on a global scale or at best a regional scale (Billè & Rochette, 2008). For example, figures on the impact on coastal infrastructures or adaptation strategies in terms of GDP points do not indicate "*who will lose out and where*", which is essential if appropriate public policies which are favourable to "losers" are to be developed. Yet the objectives, interests and reasoning of the different players (local authorities, private investors, population, etc.) with regard to climate impacts and adaptation strategies are often divergent.

The Mediterranean basin is chosen as a context for this research because of the unique combination of its natural characteristics (e.g. morphology, climate and hydrographical conditions), its environmental state (e.g. coastline stability and erosion), human related driving forces (e.g. urbanisation, industry, tourism, agriculture, fisheries, etc.) and their associated pressures (e.g. coastal development and sprawl). The vulnerability of Mediterranean coastal zones depends on sensitivity and adaptive capacity, which can vary across the Northern and the Southern shores of the Mediterranean (Bosello & Schechter, 2013). More precisely the integrated assessment exercises carried out by Bosello and Schechter (2013) point out a lower vulnerability of Euro-Mediterranean countries and a higher vulnerability of North African and Eastern-Mediterranean countries. Tourism and sea level rise are clearly the most important drivers in terms of impact (Bosello & Schechter, 2013). The high variability of sensitivity and adaptive capacity of Mediterranean coastal regions must be properly taken into account in the construction of a coastal risk assessment tool. The issues highlighted in the studies carried out under the CIRCE project reaffirm the importance of using an integrated approach that includes climate and non-climate drivers.

Tourism development represents an important non-climate driver for the vulnerability of Mediterranean coastal zones. Tourism facilities (e.g. hotels and resorts) have been built extensively in the northern part of the Mediterranean coast starting from the 1960s and continue to be developed in the southern and the Middle East shores and as a result of this sea-front development, large-scale beach and dune erosion has occurred (Satta, 2004). Problems in Mediterranean coastal zones do not stem from the impact of climate change but from the impact of unsustainable development models so far adopted by the societies concerned (Billé & Rochette, 2008). Climate change amplifies existing threats, sometimes in a decisive way by bringing out threshold effects, with ecosystem functions for example. It encourages the "over-sizing" of certain policies so as to have the latitude to cope with a very uncertain future, and above all it raises old questions by calling upon Mediterranean societies to succeed where they have failed in the past decades, i.e. to reconcile economic development with the sustainable management of coastal zones. This last is the main objective of Integrated Coastal Zone Management (ICZM). The likely magnitude of impacts like coastal erosion, flooding, saltwater intrusion over the coming decades is of great concern to policymakers, the private sector and the general public, especially with the expectation of an acceleration in SLR. In particular potential loss estimates include physical damage of residential and tourism buildings, critical facilities, and infrastructure, economic loss from business interruptions and reconstruction, and the social impacts including shelters, displaced households, and population and tourists exposure to hazards. Climate change "*impacts will not affect all the regions of the Mediterranean, and not in the same way or with the same intensity*" (Travers et *al.*, 2010) because of the diversified physical, ecological and socio-economic features at the local scale. The assessment of climate change impacts to the Mediterranean coastal zones is driven by local priorities because the "*variability of the coast, including human development patterns, result in variable impacts and adjustments along the coast, with implications for adaptation responses*" (IPCC, 2007). In this sense, just through a robust characterization of local features it is possible to robustly assess the risk to coastal hazards generated or exacerbated by climate and non-climate forcing.

This last aspect together with the uncertainty of SLR and marine storms projections is one of the major potential weaknesses for coastal risk assessment and for adaptation planning in coastal Mediterranean regions. In fact, the limitation on available data becomes one of the most relevant problems because in most locations, coastal data does not exist and also the quality of available data is uncertain due to many other factors (e.g. calibration of the measuring devices) as referred by different scientists (Snoussi et *al.*, 2008; Ozyurt, 2010). The assessment of coastal risk is therefore the result of a process of identifying, quantifying and ranking the variables of all the components characterizing the coastal system at risk: social, economic, environmental and political. In the specific case of this research the natural hazards by which risk is assessed are related to the effects of climate and non-climate forcing.

Research is needed to investigate the complex linkages and feedbacks between land use planning, climate change risks, and the socioeconomic development in coastal area with the aim of defining a more robust framework for coastal policy makers decision making process. This objective requires the establishment of a system for assessing the risk of coastal areas as a whole (natural and socio-economic system). Risk assessment represents an important 'first step' towards the integrated management and the sustainable development of coastal areas. To make this process effective it is therefore necessary to take into account an integrated approach considering all the above issues. Coastal decision makers, planners, and practitioners in the Mediterranean area have to take in consideration a number of crucial issues when implementing coastal risk assessments at the local scale. These can be resumed as follow:

- Evaluate the uncertainties regarding local projections of Sea Level Rise and other potential CC drivers like marine storms and ocean waves conditions;
- Consider the lack of local data such as: elevation, habitats, species, sediment dynamics, human settlements, infrastructure and socioeconomic indicators (McLeod et *al.*, 2010);
- Adopt and integrated approach including non-climate drivers like the contribution of other factors such as subsidence (McLeod et *al.*, 2010) and human activities like the fast growing population and increase of human activities on the coast (e.g. mass tourism). Moreover consider the combination of growing population and the increasing risks and impacts related to climate drivers;
- Define the hazard zones in the examined coastal region;
- Identify setback zones based on coastal hazard zones for human settlements, infrastructures and economic activities, providing a basis for coastal zoning and land use planning;
- Include the costal risk assessment process within the framework of the ICZM Protocol.

These issues are explored in the literature review in chapter 2, 3, 4 and 5.

1.3 Research objectives and research questions

The main objective of a coastal risk assessment is to provide coastal managers with a method to predict risks as well as provide information and to support the decision making process to take concrete actions for adaptation. In scientific literature several models and tools to assess coastal vulnerability and risk exist that differ in complexity, in the number of processes that they include, the application at various scales and in their outputs (McLeod *et al*., 2010; ETC-CCA, 2011). Dealing with the concept of risk to coastal hazards of Mediterranean coastal zones at the local level requires a specific approach that takes into consideration all the preliminary observations presented in the research rationale. The main research objective can be described as follow:

→ Define a risk assessment method, to evaluate how climate and non-climate forcing interact with existing natural hazards to impact Mediterranean coastal regions.

The specific objectives of this research coincide with the features that the coastal risk assessment method must have to satisfy the main objective of the research. These specific objectives can be resumed as follow:

- To determine a link between the conceptual framework of vulnerability and risk to climate-related hazards as defined by the recent work of IPCC published in the Fifth Assessment Report (AR5);
- To explore the possible effects of climate drivers coupled with non climate drivers on coastal areas;
- To reveal and describe linkages between susceptibility, resilience and exposure concepts within a coupled coastal socio-ecological system framework;
- To provide information to support the decision making process to take concrete actions for coastal adaptation;
- To provide a tool for a comparative analysis of coastal risk for the Mediterranean coastal regions and to support the implementation of the ICZM Protocol.
- To produce coastal risk outputs even in conditions of lack of data availability.

An overall objective is to develop a method that is easy to apply for the Mediterranean coastal managers and do not need high scientific expertise.

The most important research question concerns how to assess and communicate the future risks from climate and non-climate changes, by coupling a multiple coastal hazards approach with a socio-ecological system approach describing the complexity of Mediterranean coastal zones and to explore its use for coastal planning and ICZM. This research intends to identify data and information needed to better coordinate coastal use conflicts through land use planning so as to realize integrated and coordinated coastal management and adaptation. Some of the specific research questions are:

- What are the main climate drivers for the Mediterranean region and how can these be downscaled to the local scale?
- What are the state of the art of vulnerability and risk assessment tools?
- Is there an existing risk assessment tool suitable to the Mediterranean coastal zones?

- How to prioritize the effects of climate and non-climate forcing according to the vulnerability and exposure of coastal zones to each hazard?
- How to take into account the combined effects of multiple hazards to coastal zones?
- Is there a method to delimitate the coastal hazard zones and the setback zones?
- How to determine which variables better represents the characteristics of the coastal systems in terms of vulnerability and exposure?
- How to transfer the results of the risk assessment process into coastal risk maps?

1.4 Approach

In order to reach successfully the objectives defined for this research, the approach described in Figure 1.2 is adopted.

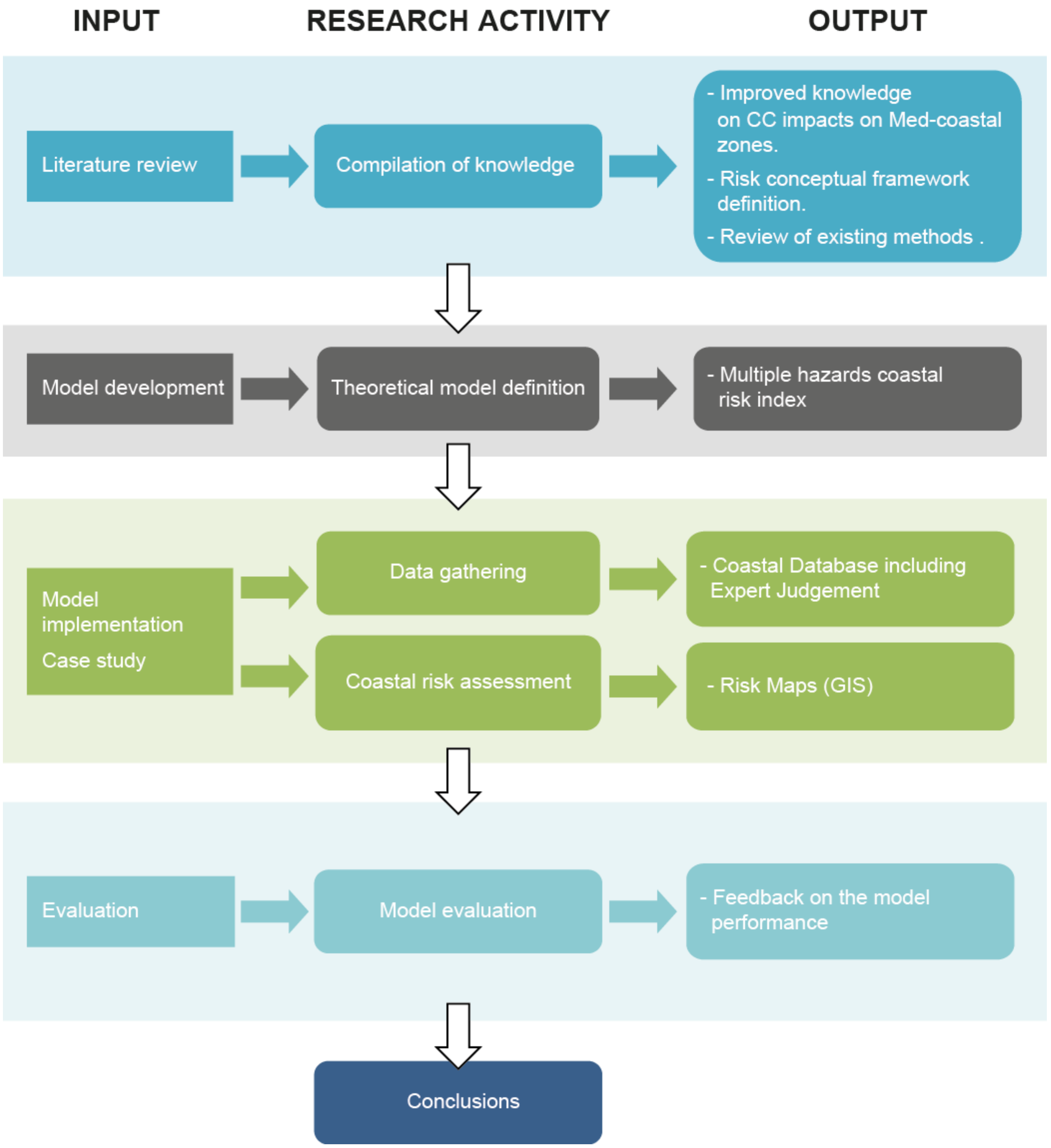


Figure 1.2 Flowchart for research activities and expected outputs.

Firstly, the review of scientific literature is carried out. The following issues are explored:

- Climate current changes and future trends in the Mediterranean;
- Non-climate drivers impacting Mediterranean coastal regions;
- To disentangle the scientific literature on DRR and CCA regarding the concept of vulnerability and risk;
- To analyse the provision of ICZM Protocol regarding the definition of a coastal setback zone to prevent natural risks resulting from coastal hazards;
- To explore the potential of ICZM as institutional and methodological framework in the Mediterranean for facilitating the dissemination of an integrated approach to risk assessment;
- To review existing vulnerability and risk assessment tools with a selection of tools more suitable to the context of the Mediterranean.

Secondly a specific coastal risk assessment method is developed.

A coastal risk index-based approach is developed to provide decision-makers at local and national level with an effective management tool, helping them to analyse and understand the risk a coastal zone is exposed to through the definition of coastal hazard zones and the prioritization of risk areas.

Thirdly, the risk assessment method is applied to a coastal destination in Sardinia being representative of different Mediterranean features. In this phase the model will be evaluated and refined.

1.5 Layout of the Thesis

Twelve chapters organized in five main sections compose this thesis: Section 1: General introduction, Section 2: Literature Review including the review of Coastal vulnerability and risk assessment methods, Section 3: Model development, Section 4: Model implementation and Section 5: Conclusions. Literature review includes 4 chapters and Model implementation 4 chapters.

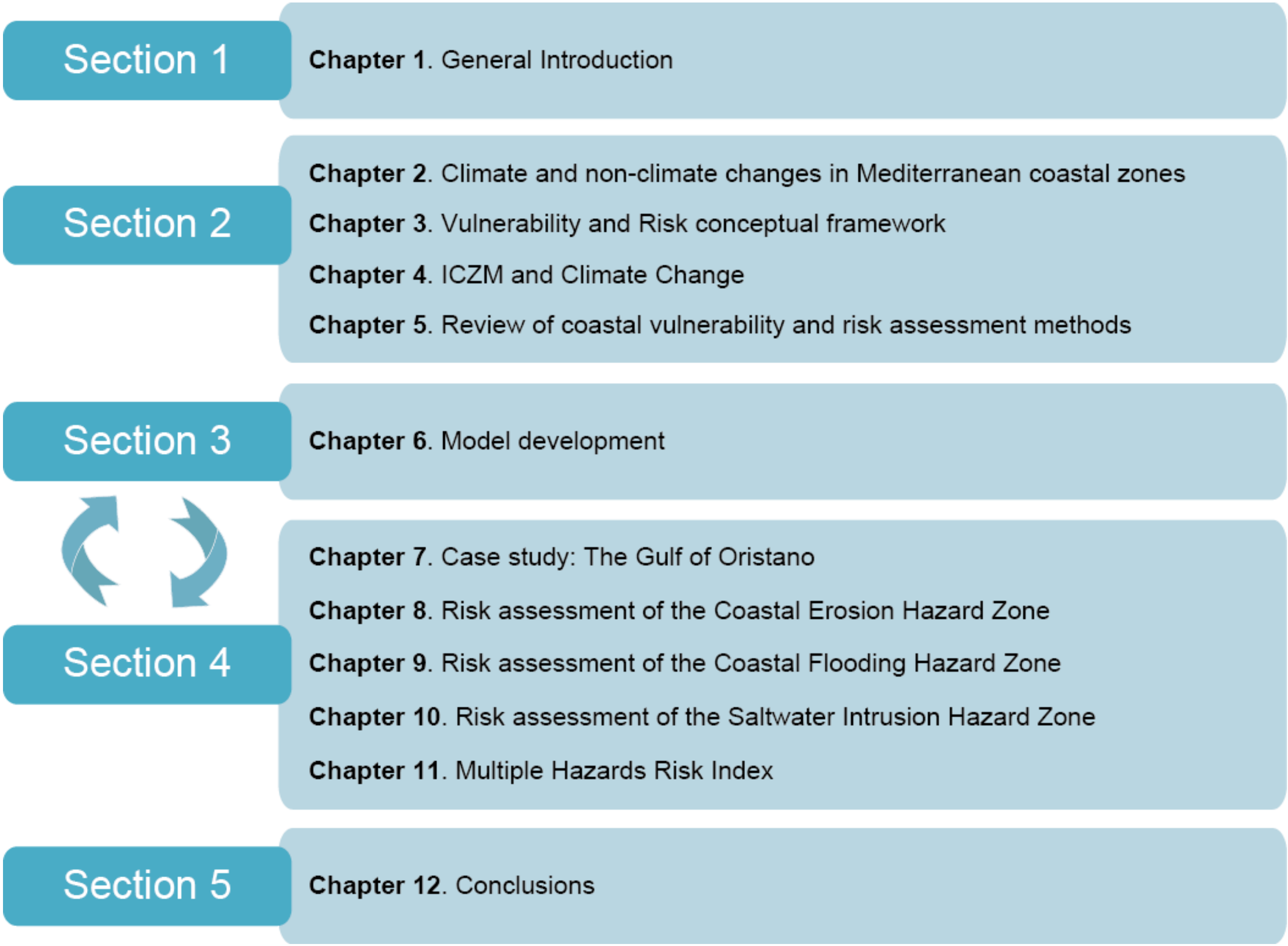


Figure 1.3 Layout of the Thesis.

CHAPTER 2. CLIMATE AND NON-CLIMATE CHANGES IN MEDITERRANEAN COASTAL ZONES

2.1 Introduction

The Mediterranean region is a complex ecosystem with a high biodiversity, which results especially vulnerable to climate change and its impacts (Gualdi et al., 2013; Rahmstorf, 2012). These impacts cause effects in a coastal environment on different levels: bio-geophysical, socio-economical, infrastructures and economic activities (Travers, 2010). Climate change forcing impacts both the bio-geophysical system (e.g. displacement of coastal lowlands and wetlands, increased coastal erosion, increased flooding, saltwater intrusion, loss of coastal habitats) and the socio-economic system (e.g. loss of property, damage to coastal infrastructure, loss of tourism, loss of cultural resources) of coastal zones. The knowledge of the potential impact of climate changes and related hazards affects land use planning and other coastal development policies. At the local level, for example, households, governments, and the private sector (e.g. tourism operators) are worried about the effects of coastal erosion on loss of properties (Neumann et al., 2000). According to the results of CIRCE project published in RACCM (Navarra & Tubiana, 2013) the major impacts of climate change in the Mediterranean coastal regions are produced by SLR and change in Storms frequencies and intensities. CIRCE models produce a 2012-2050 mean steric sea level rise projections that range between +6,6 cm and 11,6 cm with respect to the period of reference (Gualdi et al., 2013). Research on coastal vulnerability assessments and risk is mainly focused on relative SLR and less on other climate change dimensions (Nicholls et al., 2008). As a matter of fact, besides SLR, recent researches confirm that other impacts related to climate change should be considered such as a change in the frequency, intensity and spatial patterns of coastal storms, changes in wave intensity and changes in precipitation (ETC-CCA, 2011). Since the publication of AR4 (IPCC, 2007) several studies have evaluated the relative contributions of SLR and storms on projected sea level extremes “but the limited geographical coverage of studies and uncertainties associated with storminess changes prevent a general assessment” (Church et al., 2013). This chapter explores SLR and Storms physical effects on Mediterranean coastal regions as the most significant climate forcing impacting coastal systems and low-lying areas. SLR directly influences storm surges. In particular SLR current changes and future trends and associated uncertainties, key impacts on coastal zones and vulnerability hotspots in the Mediterranean will be explored. Human-induced drivers, like population growth and tourism development, the non-climate drivers, nowadays representing the most relevant stressors to coastal zones, also affect the Mediterranean coastal regions. The combined effects of climate and non-climate drivers on Mediterranean coastal regions change and related uncertainties are analysed. The specific objectives of this chapter are the following:

- To explore main features of Mediterranean climate;
- To review the global climate drivers effects on coastal systems and low-lying areas;
- To explore the dominant climate drivers and the human induced drivers for the Mediterranean coastal systems;
- To identify the coastal assets at risk;
- To identify physical and socioeconomic effects of coastal hazards;
- To identify vulnerability hotspots to climate and non-climate changes in the Mediterranean.

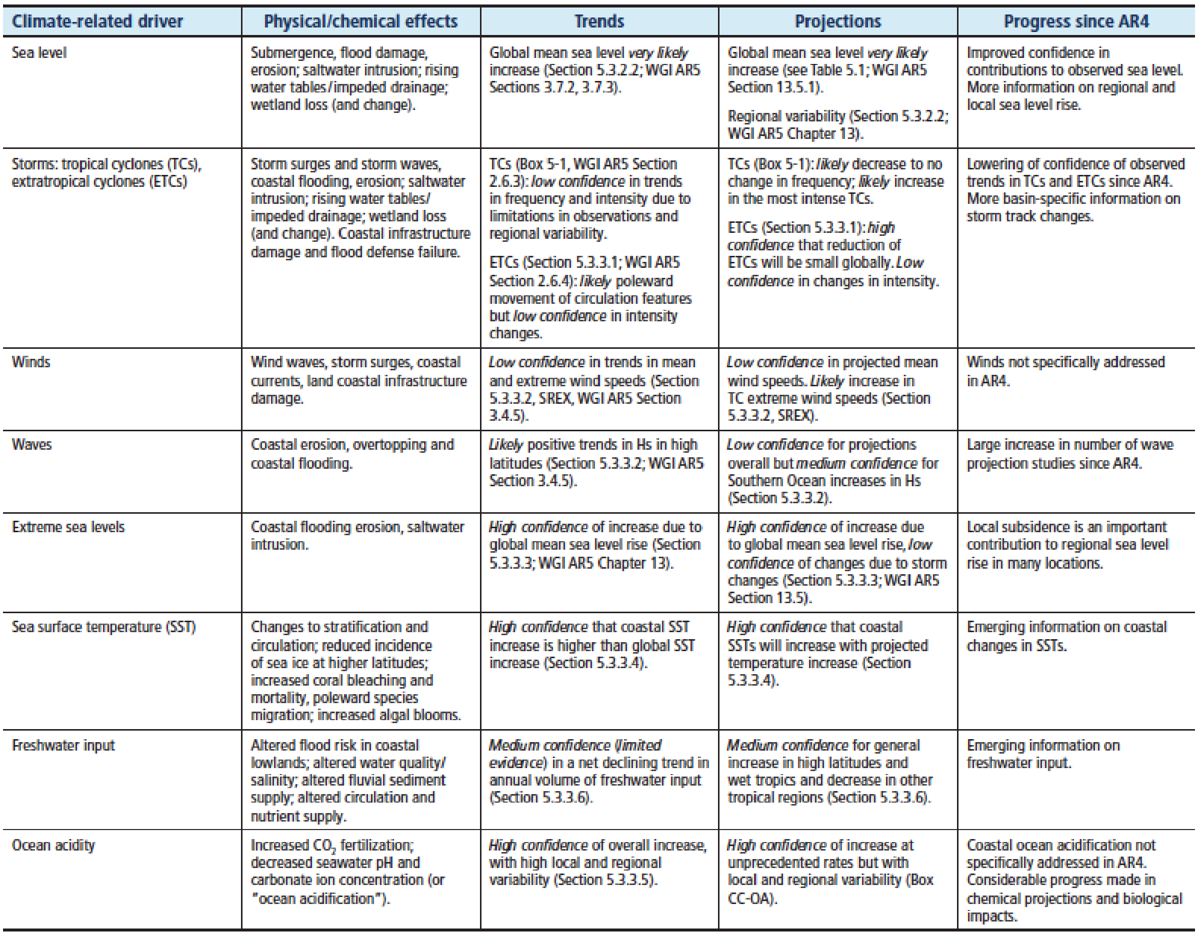
2.2 How does climate change affects coastal systems and low-lying areas?

In Chapter 6 of the Fourth Assessment Report, IPCC has identified a range of potential drivers of climate change impacts in coastal areas at the global level (Table 2.1). Impacts will be the result of the interaction between climate change drivers and between these and other drivers of change, leading to diverse effects and vulnerabilities (Nicholls et *al.*, 2007). In the same table are indicated the trends of these climate change drivers and their main physical and ecosystem effects at global level (Trend: ↑ increase; ? uncertain; R regional variability).

Climate driver (trend)	Main physical and ecosystem effects on coastal systems
CO2 concentration (↑)	Increased CO2 fertilization; decreased seawater pH (or ‘ocean acidification’) negatively impacting coral reefs and other pH sensitive organisms
Sea surface temperature (↑, R)	Increased stratification/changed circulation; reduced incidence of sea ice at higher latitudes; increased coral bleaching and mortality; pole ward species migration; increased algal blooms
Sea level (↑, R)	Inundation, flood and storm damage; erosion; saltwater intrusion; rising water tables/impeded drainage; wetland loss (and change)
Storm intensity (↑, R)	Increased extreme water levels and wave heights; increased episodic erosion, storm damage, risk of flooding and defence failure.
Storm frequency (?, R)	Altered surges and storm waves and hence risk of storm damage and flooding.
Wave climate (?, R)	Altered wave conditions, including swell; altered patterns of erosion and accretion; re-orientation of beach plan form.
Run-off (R)	Altered flood risk in coastal lowlands; altered water quality/salinity; altered fluvial sediment supply; altered circulation and nutrient supply.

Table 2. 1. Main climate drivers for coastal systems. (Source: Nicholls et al., 2007)

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 & Davidson, 2013). In recent scientific literature, extreme sea levels are those generated from combinations of different factors including tides, storm surges, wind waves and swell, and interannual variability in sea levels (IPCC, 2014b). Extreme sea levels are caused by extreme marine storms "*especially when they occur at times of high tide*" and even more "*any low-pressure system offshore with associated high winds can cause a coastal flooding event depending on the duration and direction of the winds*" (Rhein et *al.*, 2013). Since the publication of AR4 (IPCC, 2007) several studies have evaluated the relative contributions of SLR and storms on projected sea level extremes "*but the limited geographical coverage of studies and uncertainties associated with storminess changes prevent a general assessment*" (Church et al., 2013). AR5 of IPCC (2014b) reports the progresses made since AR4 in understanding the main climate-related drivers for coastal systems and in particular trends of physical and ecosystem effects (Table 2.2).



Climate-related driver	Physical/chemical effects	Trends	Projections	Progress since AR4
Sea level	Submergence, flood damage, erosion; saltwater intrusion; rising water tables/impeded drainage; wetland loss (and change).	Global mean sea level *very likely* increase (Section 5.3.2.2; WGI AR5 Sections 3.7.2, 3.7.3).	Global mean sea level *very likely* increase (see Table 5.1; WGI AR5 Section 13.5.1). Regional variability (Section 5.3.2.2; WGI AR5 Chapter 13).	Improved confidence in contributions to observed sea level. More information on regional and local sea level rise.
Storms: tropical cyclones (TCs), extratropical cyclones (ETCs)	Storm surges and storm waves, coastal flooding, erosion; saltwater intrusion; rising water tables/ impeded drainage; wetland loss (and change). Coastal infrastructure damage and flood defense failure.	TCs (Box 5-1, WGI AR5 Section 2.6.3): *low confidence* in trends in frequency and intensity due to limitations in observations and regional variability. ETCs (Section 5.3.3.1; WGI AR5 Section 2.6.4): *likely* poleward movement of circulation features but *low confidence* in intensity changes.	TCs (Box 5-1): *likely* decrease to no change in frequency; *likely* increase in the most intense TCs. ETCs (Section 5.3.3.1): *high confidence* that reduction of ETCs will be small globally. *Low confidence* in changes in intensity.	Lowering of confidence of observed trends in TCs and ETCs since AR4. More basin-specific information on storm track changes.
Winds	Wind waves, storm surges, coastal currents, land coastal infrastructure damage.	*Low confidence* in trends in mean and extreme wind speeds (Section 5.3.3.2, SREX, WGI AR5 Section 3.4.5).	*Low confidence* in projected mean wind speeds. *Likely* increase in TC extreme wind speeds (Section 5.3.3.2, SREX).	Winds not specifically addressed in AR4.
Waves	Coastal erosion, overtopping and coastal flooding.	*Likely* positive trends in Hs in high latitudes (Section 5.3.3.2; WGI AR5 Section 3.4.5).	*Low confidence* for projections overall but *medium confidence* for Southern Ocean increases in Hs (Section 5.3.3.2).	Large increase in number of wave projection studies since AR4.
Extreme sea levels	Coastal flooding erosion, saltwater intrusion.	*High confidence* of increase due to global mean sea level rise (Section 5.3.3.3; WGI AR5 Chapter 13).	*High confidence* of increase due to global mean sea level rise, *low confidence* of changes due to storm changes (Section 5.3.3.3; WGI AR5 Section 13.5).	Local subsidence is an important contribution to regional sea level rise in many locations.
Sea surface temperature (SST)	Changes to stratification and circulation; reduced incidence of sea ice at higher latitudes; increased coral bleaching and mortality, poleward species migration; increased algal blooms.	*High confidence* that coastal SST increase is higher than global SST increase (Section 5.3.3.4).	*High confidence* that coastal SSTs will increase with projected temperature increase (Section 5.3.3.4).	Emerging information on coastal changes in SSTs.
Freshwater input	Altered flood risk in coastal lowlands; altered water quality/ salinity; altered fluvial sediment supply; altered circulation and nutrient supply.	*Medium confidence* (*limited evidence*) in a net declining trend in annual volume of freshwater input (Section 5.3.3.6).	*Medium confidence* for general increase in high latitudes and wet tropics and decrease in other tropical regions (Section 5.3.3.6).	Emerging information on freshwater input.
Ocean acidity	Increased CO_2 fertilization; decreased seawater pH and carbonate ion concentration (or "ocean acidification").	*High confidence* of overall increase, with high local and regional variability (Section 5.3.3.5).	*High confidence* of increase at unprecedented rates but with local and regional variability (Box CC-OA).	Coastal ocean acidification not specifically addressed in AR4. Considerable progress made in chemical projections and biological impacts.

Table 2. 2. Main climate-related drivers for coastal systems, their trends due to climate change, and their main physical and ecosystem effects. (Source: IPCC, 2014b)

Globally the climate related driver's trends (IPCC, 2014b) affecting coastal systems can be resumed as follow:

- Very likely increase of mean sea level;
- Low confidence in storms change in frequency and intensity trends due to limitation of observations;
- Low confidence in trends mean extreme winds;
- High confidence of increase of extreme sea level due to increase of mean sea level rise;
- High confidence of SST increase;
- Medium confidence of freshwater input increase.

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 notwithstanding. For example, some scientific studies suggest an increase in extreme sea levels due to storm while others say the exact opposite (IPCC, 2014b). This uncertainty is due to the small number of studies on a regional scale and the use of different models to simulate the atmospheric forcing (IPCC, 2014b). However, as reported by WGI contribution to AR5, observed trends of SLR indicate that "it is likely that extreme sea levels have increased since 1970, largely as a result of the rise in mean sea level" (Rhein et al, 2013) and "*coastal systems and low-lying areas will increasingly experience extreme sea levels and their adverse impacts*" (IPCC, 2014b).

In this research we focus on climate drivers that have direct physical impacts on coastal systems (e.g. erosion, coastal flooding) like SLR, storms, waves and extreme sea levels. In this sense, we do not consider SST and Ocean acidity that generate ecosystem effects (e.g. algae blooms). We consider the indirect role of freshwater input in contributing to the flood risk in coastal lowlands, but we do not consider freshwater input from extreme precipitation as a climate forcing for this research. 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).

What emerges from this first review of the scientific literature regards the primary role of SLR forcing in impacting coastal system and low-lying areas on which it exists a full scientific consensus. SLR directly influences storm surges and wind waves exacerbating their effects. Rising sea level means higher storm surges, which increases the risk for coastal flooding[1]. Severe storms

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[1] UCSUSA - http://www.ucsusa.org/global_warming/science_and_impacts/impacts/hurricanes-and-climate-change.html#.VFD-MouG8Qk (accessed Aprli 21, 2014)

can also produce storm surges over coastal seas, and their amplitude depends on "*the storm track, regional bathymetry, nearshore hydrodynamics, and the contribution from waves*" (IPCC, 2014b).

We can conclude that two most relevant climate drivers are the mean sea level rise (SLR) and storms in their contribution to generate the extreme sea levels (e.g. combination of tides, surges and waves).

From these considerations two important research questions emerge:

- How to deal with global SLR projections uncertainties?
- Given the lack of regional studies and uncertainties associated with storminess changes is it still possible to assess sea level extremes?

We try to disentangle these two questions in the next sections.

2.2.1 Global mean sea level rise and uncertainties of future projections

Thermal expansion due to ocean temperature increases and mass input due to melting glaciers and ice sheets are the primary components responsible for SLR (Petersen et al., 2007). Both of these inputs are driven by increases in atmospheric greenhouse gas concentrations, the resultant earth energy imbalance and subsequent warming (Petersen et *al*., 2007). As reported in Summary for Policy Makers of the contribution of WG I to the AR5 (IPCC, 2013), the mean global level rose by 0.19 [0.17 - 0.21] m over the period 1901 to 2010 (IPCC, 2013). Projections of global mean sea level rise reported in chapter 13 of AR5 (Church et al., 2013), are larger than in the AR4, "*primarily because of improved modelling of land-ice contributions*" (Church et *al*., 2013). Authors report that for RCP8.5, the worst analysed scenario, the rise by 2100 is 0.52 to 0.98 m with a rate during 2081–2100 of 8 to 16 mm yr–1 (Church et al., 2013) much higher compared to predicted global sea level changes in AR4 ranging from 0.18m to 0.59m by 2090 (IPCC, 2007). Sea-level will continue to rise for centuries, even if GHG concentrations are stabilized, with the amount of rise dependent on future GHG emissions (Church et al., 2013).

The uncertainty of projection and future scenarios increases from global to regional/local scale and at the local scale the change of Sea Level can deflect from the global mean change of Sea Level for several reasons (Rahmstorf, 2012). First of all ocean waters moves due to wind and other factors, the global mean ocean level doesn't change, but there is an alteration in sea level at regional scale, it happens due to natural oscillation of climate system and anthropogenic changes (Rahmstorf, 2012). Whenever the ice melts, there is a reduction of gravitational pull of land ice, which has a big effect in water surface. Locally the sea level change relative to the land is determined by land vertical movements, which is due to natural (tectonic movements) and anthropogenic factors (groundwater and oil extraction) (Rahmstorf, 2012). All these aspects can be modelled, but still there are uncertainties. The changes of oceanic circulation are difficult to model and because of the issues related to ice melting, it's necessary to know the global balance and where the ice melts. The local land movements, in a long time scale, happen with a constant rate, but the information about these movements aren't available everywhere, so locally, the movements can change due to local effects (e.g. melting of ice at local scale).

If on one-side predictions of future SLR depends substantially on the global warming scenario, on the other side ocean thermal expansion in the next future is likely to increase even in a scenario of global warming reduction. This is due to the relative slow thermal exchange between ocean and atmosphere. Uncertainties related to SLR estimates are mostly due to uncertainty about how much water will be lost from ice sheets (UNFCCC, 2007). The most significant concern regarding the SLR in the 21st century is how much ice will be lost from the Greenland and Antarctic ice sheets as a result of rapid accelerations in ice flow (Lowe & Gregory, 2007). Simple kinematics and observations of current velocities of marine-terminated glaciers in Greenland and West Antarctica suggest that future ice-dynamics discharge could lead to SLR of about 0,80 meters by 2100 (Pfeffer et al., 2008).

Overall, the local sea level change can differ from global sea level of some tens of centimetres. Some coastal zone (like the low delta cities) can be particularly affected by this local effect (Rahmstorf, 2012). To evaluate SLR, it is necessary to know the sum of global, regional and local tendency relative to mutating oceans and land levels (Rahmstorf, 2012).

One of the best-known applications for global and regional SLR record is the PSMSL. This data set is the main source of information on long-term changes in global sea level during the last two centuries. A better understanding of climate real threats needs accurate predictions of SLR both generated from thermal expansion, than from melting of glaciers and ice caps (included Antarctica and Greenland) contributions. The analysis on future SLR projections should focus on understanding these physical contributions that control SLR including the low probability and high consequence scenario where scientific knowledge is inadequate. A strategy based on two parallel actions is needed. On one hand, advance in the scientific understanding of observed and future climate-induced SLR is required and, on the other hand, the development of pragmatic impact and adaptation scenarios to capture the uncertainties of future SLR must become a priority for policy makers. Another very critical aspect derives from the fact that conducting a vulnerability assessment study at the local level requires more knowledge to be gathered in terms of high spatial resolution and vulnerability information. The risk assessment model at a local scale should take into account the use of downscaling techniques to provide sea level, storm surge and wave information at that particular scale. The accuracy improvement of climate change models will allow scientists and practitioners to better predict physical impacts on coastal zones.

2.2.2 Extreme marine storms and extreme sea levels

Studies of severe marine storms are limited, and if exist, most analyses have focused on particular regions (Rhein et al., 2010). Marine storms are characterized by several variables (wave height/energy, wind speed/direction, atmospheric pressure, wave direction, storm duration, beach state, water level), which are very difficult to define and to predict (Barnard, 2013).

Extreme sea levels represent the measurable effects of an extreme marine storm along the coast (Rhein et al., 2010).

The analyses carried out on existing tide gauge records since 1970s show that the magnitude of extreme sea level events has increased in all regions and “the height of a 50-year flood event has increased anywhere from 2 to more than 10 cm per decade since 1970” (Rhein et al., 2010). Chapter 13 of the contribution of WGI to AR5 summarize that “it is very likely that there will be an increase in the occurrence of future sea level extremes in some regions by 2100, with a likely increase in the early 21st century” (Rhein et al., 2010). Moreover future sea level extremes will be affected by the combined effects of SLR and changes in storminess and while “there is high confidence that extremes will increase” with the increase of sea level, there is yet “low confidence in region-specific projections in storminess and storm surges” (Rhein et al., 2010). We can conclude that is very likely the combined effects of SLR and severe storms cause extreme sea level events. Another non-climate component that plays an important role in generating sea level extremes is the astronomical tide. Figure 2.1 illustrates the effects of extreme sea levels on impacting the coastal system.

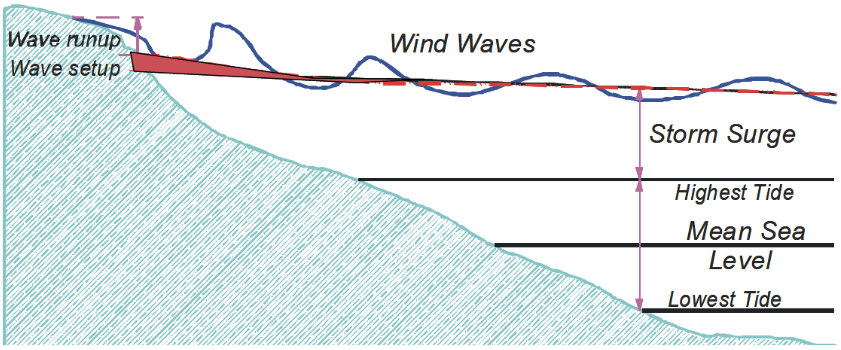
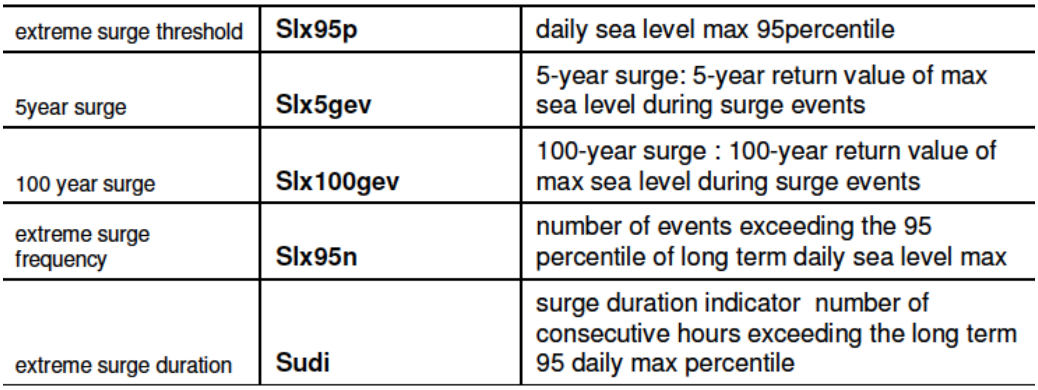


Figure 2.1 Extreme sea levels including the contribution of tide. (Source: McInnes et *al.*, 2009).

Extreme sea levels are the combination of tide (climate independent variable) with storm surges due to the action of storms and winds (Marcos et *al.*, 2009). Storm surge is a climate forced long wave motion that can produce important elevation of the water surface. Surges ordinarily are associated with tropical storm or mid-latitude storm (Ozyurt, 2007). In the areas with a large tidal range, the events of storm surge are especially pronounced. In the case of the Mediterranean coastal zones, sea level extremes are mainly caused by storm surges rather than by the combination of tides and surges (Marcos et *al.*, 2009). Storm surge is considered as “*the temporary increases in coastal sea levels caused by the falling atmospheric pressure and severe winds during storms*” (McInnes et *al.*, 2009). According to NOAA “*Storm surge is the abnormal rise in water level, over and above the regular astronomical tide, caused by a severe storm*”[2].

The storm surge is generally accompanied by an additional increase in water level due to the cumulative effect of breaking waves on the coastal system, which produces wave setup. The magnitude of the wave setup is related to the height of the offshore waves and is usually much smaller than the storm surge. A very important parameter for measuring the effects of coastal flooding and coastal erosion is “wave run up” defined as the maximum inland penetration of water caused by waves breaking on the coast (McInnes et *al.*, 2009).

Various statistical measures are used to measure sea level extremes such as annual maximum surge, annual maximum surge-at-high-water, monthly mean high water level, changes in number of high storm surge events, or changes in 99th percentile events (Rhein et *al.*, 2010). Lionello (2009) proposes a number of indicators to measure sea level extremes based on the measure of surges (Table 2.3).



extreme surge threshold	**Slx95p**	daily sea level max 95percentile
5year surge	**Slx5gev**	5-year surge: 5-year return value of max sea level during surge events
100 year surge	**Slx100gev**	100-year surge : 100-year return value of max sea level during surge events
extreme surge frequency	**Slx95n**	number of events exceeding the 95 percentile of long term daily sea level max
extreme surge duration	**Sudi**	surge duration indicator number of consecutive hours exceeding the long term 95 daily max percentile

Table 2. 3. Sea level extremes indicators. (Source: Lionello, 2009)

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[2] NOAA website - http://www.stormsurge.noaa.gov/ (accessed 15th of July 2014)

2.2.3 Interaction between sea level rise and storm surges

Sea level rise and intensified marines storms due to climate change interact generating more severe impacts on coastal systems and low-lying areas. Figure 2.2 illustrates how sea level and storm surge interact in normal conditions and in conditions of intensified storms.

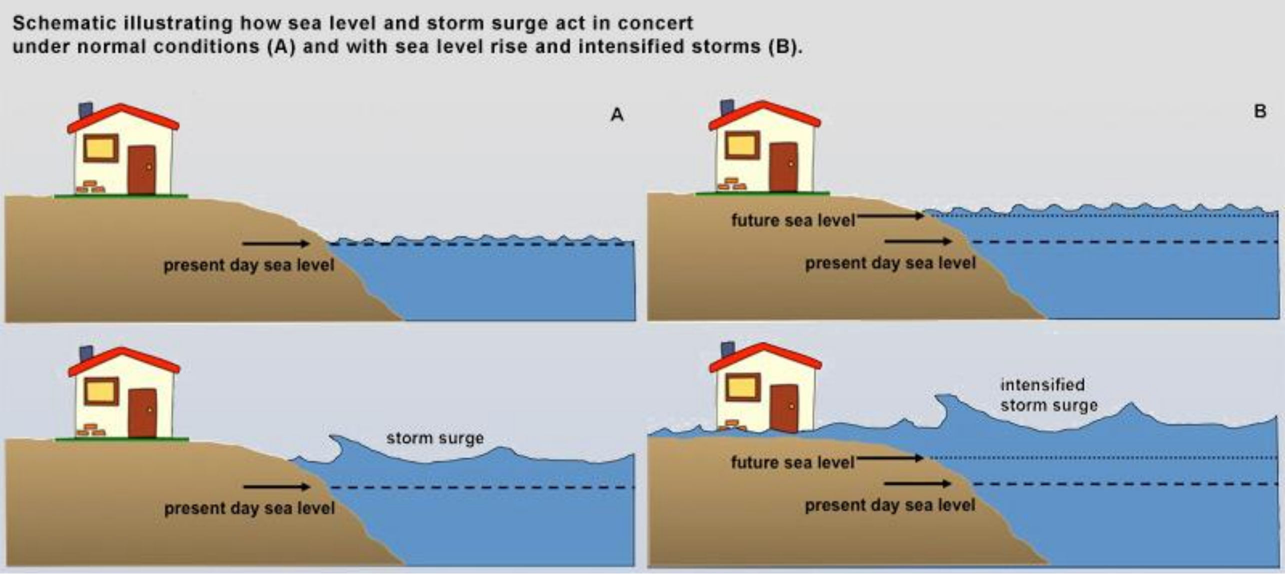

Figure 2.2 Effects of storm surges and storm surges coupled with SLR.
(Source: www.centerforoceansolutions.org/ accessed 15th of July 2014).

A simple method for the calculation of the effects of SLR on storm surges is the following one proposed by Dasgupta (2009) based on the work of Nicholls et al. (2008) and DIVA databases. Future storm surges are calculated as follow:

Current storm surge = S100

Future storm surge = S100 + SLR + (UPLIFT * 100 yr) / 1000 + SUB + S100 * x

Where:

S100 = 1-in-100-year surge height (m)

SLR = sea-level rise (1 m)

UPLIFT = continental uplift/subsidence in mm/yr

SUB = 0.5 m (applies to deltas only)

x = 0.1, or increase of 10%, applied only in coastal areas currently prone to cyclones/hurricanes

2.3 Climate changes in the Mediterranean basin

2.3.1 Main features of the Mediterranean climate

The climate of the Mediterranean region "*is characterized by the interaction between mid-latitude and sub-tropical regimes and the complex morphology of mountain chains and land-sea contrast*" (Gualdi et *al.*, 2013). The Mediterranean Sea is a marginal sea, and the system Mediterranean/Black Sea has a semi-enclosed nature, connected to the Atlantic Ocean through the Strait of Gibraltar. The region is in a transitional zone which has a complex morphology (the Mediterranean basin is like a lake with high peninsulas and mountain barriers), so the climate in the Mediterranean region is characterized of unique climatic conditions (wet winters and dry summers with high variation, during the year, in rainfall and frequent droughts and dry spells) and the consequences in water cycle are very substantial. Increases in evaporation from the sea and in fresh water evaporation from the land, have great effects in salt, water and energy budgets and consequences in Mediterranean Sea salinity, sea level and circulation, the last one is 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 great gradient, due to the interaction between two systems: 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, which is affected by northerly continental winds. Thus the wind regime is very important in the heat budget. In addition, during the winter weather, cyclonic disturbance (causing wind storm), influence the Mediterranean climate (Gualdi et *al.*, 2013). Average annual air temperature increases in the Mediterranean and is estimated to be slightly higher than at the world level (Hallegatte et *al.*, 2007) with a value estimated in the range 2°C - 6.5°C by the end of the century (Travers et *al.*, 2010). Sea Surface Temperature (SST) increase generates thermal expansion of seawater and consequently further sea level rise (ETC/ACC, 2010). The European funded project CIRCE shows a detailed scenario of climate change impacts of the Mediterranean region. The change of near-surface temperature, in the recent past, is coherent with the observations, which prove that the Mediterranean region was affected by heating, during the 20th century. From 1951 to 2000, the mean heating tendency was 0,1° ± 0,04°C/decade. The change of precipitation points out a tendency to a dry condition (above all in summer months). Overall the change of precipitation in the period 2021- 2050 is approximately 5% (Gualdi et *al.*, 2013). The precipitation and temperature tendency, evaluated in the CIRCE project, are associated to a greatest change, about the Mediterranean basin and its hydrologic cycle. The balance evaporation-precipitation shows a positive result in the sea and neighbouring land, cause of the rise of evaporation and the decrease of precipitation. The main impacts of climate change in the Mediterranean Sea region are changes in sea surface temperature and precipitation, changes in the water budget, changes in the Mediterranean heat budget and SLR (Rahmstorf, 2012). Mediterranean coastal regions show high biodiversity concentration than any other region of the world; they contain a great number of endemic species, which make them vulnerable to climate changes. The project CIRCE, and in particular Research Line 7 (Ecosystem Services), was devoted to the evaluation of the vulnerability of ecosystem services in the Mediterranean region to climate change and other forcing. The multidisciplinary research aimed to address 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 Mediterranean region (Hoff, 2013). The RL7 highlights how diversity in biophysical and socio-economic aspects characterizes the Mediterranean region and above all the differences between the northern and the southern Mediterranean and the southern and eastern Mediterranean. There is large scientific consensus on Global Climate Models projections on how decreasing precipitation and increasing temperatures in the southern and eastern Mediterranean will exacerbate aridification, land degradation, and desertification in this region (Hoff, 2013). The southern and the eastern Mediterranean countries are more vulnerable than northern countries not only because of projected aridification but also for great climate variability and lower adaptive capacity (Hoff, 2013). Above all, water availability and water quality degradation (e.g. from pollution, overexploitation or increasingly also from seawater) have become limiting factors for Mediterranean social and ecological systems (Hoff, 2013). The water scarcity problem in some Mediterranean countries (e.g. Jordan is a country with the lower per-capita water availabilities) in combination with expected climate changes like the increase of temperature and the decrease of precipitation, will reduce runoff, groundwater minimum recharge and consequently water quality and 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 (due to change of atmospheric pressure, increase of temperature and oceans expansion) has a significant role in the salt-water intrusion process.

2.3.2 Mean Sea Level Rise current changes and future trends in the Mediterranean

The level of isolation of the Mediterranean basin, influences the range of sea level from a value of 14 cm (Mediterranean completely isolated, with dominant halosteric effects) to a rising of sea level due to the Atlantic oceans, where disturbances propagate undisturbed in the entire Mediterranean basin, in this last case, sea level can change from 20 to 200 cm in a 2100 scenario (Umgiesser et *al.*, 2010). Because the Mediterranean has a negative hydrologic balance, what it loses for evaporation, doesn't compensate what arrives with precipitation and rivers. For this reason, the sea level in the Mediterranean should decrease, on the contrary, there's an increase in the sea level due to the water from the Atlantic (principle of communicating vessels). Another effect due to the strong evaporation in the Mediterranean is the salinity increase (Rippa, 2012). To obtain a realistic climate prevision is very difficult. For example, the general circulation model CMIP3 (Meehl et *al.*, 2007) presents some difficulties in the prediction of present climate, because of their low spatial resolution, indeed these results models should be regarded with caution. A few studies have been carried out about the climate change impacts in the Mediterranean basin and these studies have been conducted with the consideration of only one climate model, not considering the uncertainty due to the model selection. Thorpe and Bigg (2000) and Somot et al. (2006) performed two studies, which underlined an increase of SST (sea surface temperature), SSS (sea surface salinity) and also a change in runoff water at the Strait of Gibraltar (Gualdi et *al.*, 2013). Changes in temperature and salinity involve changes in water density, which is also reflected on the sea level. This is the "'steric effect", characterized by an increase of the level on the occasion of heating the water and by its decrease at an increase of salinity. In the Gulf of Trieste, in the Adriatic Sea, the steric effect of the secular trend, about -4mm/century, is negligible compared to the level observed in the order of 100 mm /century[3].

In the Mediterranean we have two types of Sea Level observations. Tide gauges which go back to the late nineteenth century but only with local measures and satellite altimetry available since about 1993 (Navarra & Tubiana, 2013). Sea level records starting from the beginning of the 1900s exist in Marseille, Genoa, Trieste and Venice showing a range of 1.1–1.3 mm/year (Ulbrich et *al.*, 2013). The CIRCE project assumes that the possible Seal Level change is represented approximately only by the steric effect (SE) component (Gualdi et *al.*, 2013). The main novel characteristic that distinguishes the CIRCE models from state-of-the-art climate models commonly used to produce scenario simulations is the inclusion of a realistic representation of the Mediterranean Sea into the climate system (Gualdi et *al*. 2013). Within the CIRCE project, there are five regional ocean models dedicated to the Mediterranean Sea and used for mean SLR tendency here listed:

1. NEMO-MED16 used at INGV and simply called INGV
2. MITgcm used at ENEA and simply called ENEA
3. NEMOMED8 used at Meteo-France/CNRM, and simply called CNRM

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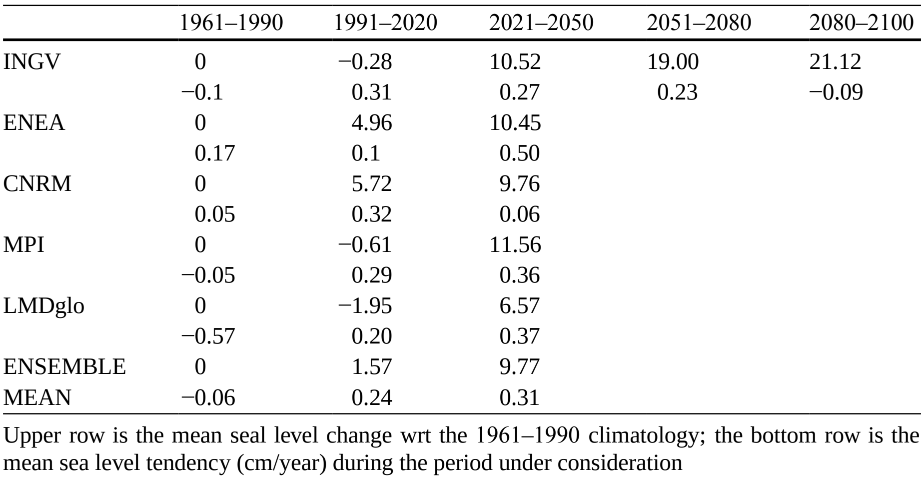
[3] ISMAR – CNR http://www.ts.ismar.cnr.it/node/36 (accessed31 January, 2013)

4. MPIOM used at MPI and simply called MPI
5. LMDglo of IPSL simply called LMDglo

Time-series of the SLR averaged over the Mediterranean Sea obtained from the CIRCE models integrations cover the 1950–2050 period, except for INGV that covers also the period from 2050 to 2100 (Gualdi et *al.*, 2013). Gualdi et *al.* (2013) uses the 1961–1990 trends as a proxy of model performances within the present climate conditions. In table 2.3, SLR time series are reported for the five models.



	1961–1990	1991–2020	2021–2050	2051–2080	2080–2100
INGV	0	−0.28	10.52	19.00	21.12
	−0.1	0.31	0.27	0.23	−0.09
ENEA	0	4.96	10.45		
	0.17	0.1	0.50		
CNRM	0	5.72	9.76		
	0.05	0.32	0.06		
MPI	0	−0.61	11.56		
	−0.05	0.29	0.36		
LMDglo	0	−1.95	6.57		
	−0.57	0.20	0.37		
ENSEMBLE	0	1.57	9.77		
MEAN	−0.06	0.24	0.31		

Upper row is the mean seal level change wrt the 1961–1990 climatology; the bottom row is the mean sea level tendency (cm/year) during the period under consideration

Table 2. 4. Time average for the mean Sea Level for the five models used for the CIRCE project. (Source: Gualdi et *al.*, 2013)

The first consideration that can be done is that all models in the period 1991-2020 confirm a very low increase of SLR (1.57 cm) and a trend of 0.24 cm / year. The differences between ENEA and CNRM models, which estimate an increase of the SLR and other models, such as INGV and LMDglo, which estimate a decrease of SLR, still demonstrate a high degree of uncertainty. As for the period 2020-2050, the models differ little from an average growth of SLR, equal to 9.77 cm, with a trend of growth was 0.31 cm / year.

2.3.3 Extreme ocean wave conditions and extreme sea levels

Extreme waves pose severe hazards for shipping, offshore activities, for beaches and for ports and the assessment of their change in the Mediterranean it’s very important especially for coastal planning and for small ships routing (Ulbrich et al., 2013). Extreme waves are caused by strong winds offshore, and they are mostly associated with cyclones (Lionello, 2009).

Analysis of extreme waves is based on the Significant Wave Height (SWH), which represents a "*statistical parameter that is proportional to the total variance of the sea surface and a good representation of the visual estimate of wave height at sea*" (Ulbrich et *al*., 2013). The indicator that is generally used to assess extreme waves is SWHx95p (Lionello, 2010; Ulbrich et *al.*, 2013). SWHx95p is the wave threshold that is reached every season for a few days and "*it is derived from the statistical distribution computed for a relatively short period (1-5 year long) and its variability describes the level of the extreme wave events which rarely but regularly happen in a season*" (Lionello, 2010).

In general extreme SWHs are associated to strong winds with a long fetch and the highest values measured in the western Mediterranean are generated by Mistral wind (Ulbrich et *al.*, 2013).

As we've discussed in the previous section sea level extremes are mainly caused by storm surges (Marcos et *al*., 2009). For each Mediterranean coastal region the storm surge events exhibit substantial diversity due to different aspects like topography, direction characteristics and storm magnitude (Krestenitis et *al.*, 2014). Coastal Flooding produced by storm surges represent a relevant issue for the Mediterranean coastal zones and are documented by several case studies (Conte & Lionello, 2014). Extreme waves also raise coastal water levels and ride on top of the storm surge to cause extreme damage. The evolution of the sea level depends on morphological differences between the Mediterranean regions, above all on the frequency and magnitude of the extreme events. Conte and Lionello (2014), conducted a study about the characteristics and evolution of the storm surge distribution along the Mediterranean coast, the results show that in the North Adriatic and the gulf of Gabes happen the largest surges and in the future climate change scenarios the situation do not change. Also in the gulf of Lion, in the northern Aegean and the Gulf of Alexandretta there are another maxima (Conte & Lionello, 2014).

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). 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). Brecht et *al.* (2012) indicates two reasons why climate change can intensify storm surges. First, storm surges will be raised by accelerated SLR and second, as summarized by IPCC (2011), warmer ocean water is likely to intensify cyclone activity and heighten storm surges (Brecht et *al.*, 2012). An increase of storm surges, will generate more damaging flood conditions in coastal zones and particularly in low-lying coastal areas and these impacts will be even more severe when storm surges are accompanied by extreme waves driven by strong winds (Brecht et *al.*, 2012). The storm impact is a function of different parameters: intensity of the storm, width and slope of mainland, climate characteristics (wind and wave), geometry of local features, susceptibility of the coastal area and dynamic change during the storm (Ozyurt, 2007). The effects of cyclones passing over Europe and the triggering of Lee cyclones, consistently induces waves and storm surge activity over the northern basins of the Mediterranean (Ulbrich et *al.*, 2013). In this respect several studies have considered in detail the Gulf of Lions and the northern Adriatic (Ulbrich et *al.*, 2013; Lionello 2008, 2010, 2012). Atmospheric aspects like the pressure distribution and winds are still investigated for the variation and evolution of the extreme events (Krestenitis et *al.*, 2014).

Conte and Lionello (2014) have studied the effects of climate changes on storms integrating studies carried out in several Mediterranean coastal zones contributing with new information to the existing scientific literature because their study is based on a new set of climate simulations and datasets produced in the CIRCE project (Conte & Lionello, 2014). Conte and Lionello (2014) use CIRCE climate scenarios coupling the evolution of means sea level pressure (MSLP) with surface wind fields for the computation of sea level extremes. The indicators used by Conte and Lionello (2014) that describe storm surge events are called positive and negative storm index. Positive surges are produced by pressure minima and wind blowing towards the shore in shallow waters, and negative surges are produced by pressure maxim and offshore winds (Conte & Lionello, 2014). According to the results of their analysis "*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. To mitigate the effects of storm surge events, it is possible to provide and implement some activities that address different fields: to improve the coastal defences and the meteorological forecasting (evacuate high-risk areas when storm surge is forecasted), identifying the areas with an active risk (risk maps) and develop local and national mitigation plans, curb global warming and its effects (Micallef, 2011). The coastal flooding has considerable consequences on the economy, therefore, is necessary a right prediction for the coastal population. From the end of 2002, ICPSM (Centre for the sea level forecasting and flood warnings of the Venice Municipality) created a system for the Storm surge forecast; it is based on a finite element hydrodynamic model. With the aim to extend spatially the prediction and to increase the accuracy, in the last years the system has been developed and improved (Bajo et *al.*, 2010). A new tool for storm surges forecasting in the Mediterranean, named KASSANDRA, has been recently developed. KASSANDRA provides daily forecasts, to maximum four days each, for the Mediterranean and Black seas at steps of 3 hours for the total water level, surface currents and significant wave height (Ferrarina et *al.*, 2013).

We can conclude that the maximum trend of extreme waves and extreme sea levels (storm surges) are caused by changes in sea levels and marine storms events with high winds. The combined effects of extreme waves and storm surges create the conditions for maximum risk for coastal areas. While the measurement of the average values of SLR is made with a relative simplicity of models based on tide gauges or on satellite data, current observations and trends of marine storms present more uncertainties (Ulbrich et *al.*, 2013). SWHx95p and SLHx95p represent two useful indicators to describe respectively extreme waves and extreme sea levels (Lionello, 2009).

2.4 The human induced forcing on Mediterranean coastal zones

With the aim of preparing sound coastal adaptation strategies, coastal risk assessment method should follow an integrated assessment approach including non-climate changes and their interaction (ETC-CCA, 2011). Notwithstanding coastal systems suffer enormous pressures from direct, and indirect effects resulting from several human-induced drivers linked to population and economic growth non-climatic environmental and socio-economic changes are often disregarded in the coastal vulnerability assessment research (Nicholls et *al.*, 2008). Hence for the formulation of appropriate management strategies, it is necessary to evaluate the interactions between climate and non-climate drivers (UNEP & EEA, 1999). In the assessment of climate change forcing and its impacts on coastal zones it is important to consider non-climate drivers and their mutual interaction, like land use change, urbanization and the development of activity related to tertiary sector, like tourism (Hoff, 2013; Billé et *al.*, 2013; Nicholls et *al.,* 2008). For the formulation of long-term adaptation strategies, climate change is not the only driver "*and not even the main one in many cases*" (Billé et *al.*, 2013). Furthermore other non-climate changes like local demographics, future political choices, and evolution of tourism demand present high level of uncertainties (Billé et *al.*, 2013).

As reported by Chapter 5 of AR5 (IPCC, 2014b) population growth, economic development and urbanization represent a primary driver of change for coastal systems. The most relevant non-climate drivers in the Mediterranean are the fast growing of population and coastal tourism development and the associated increasing impacts over the coastal zones like increase of land use, water and groundwater use, sediment supply, etc. (UNEP-MAP, 2012). As reported by UNEP-MAP (2012), the total population grew from 276 million in 1970 to 412 million in 2000 (1,64 % increase per year) and to 466 million in 2010 (1,35 %). Other non-climate driver is the vertical land movement (uplift and subsidence) that can be generated by tectonic, glacial isostatic, sediment compaction or fluid withdrawal (Burkett et *al.*, 2012). .

2.4.1 Population growth

Fast and deep socio-economic changes, independent of climate issues, played a crucial role in the last decades, and they are expected to grow in the 21thcentury. The total population of the Mediterranean countries grew from 276 million in 1970 to 412 million in 2000 (a 1,64 % increase per year) and to 466 million in 2010 (1,35 % increase per year) (Plan Bleu, 2012). Moreover is estimated that the population will reach 529 million by 2025 (UNEP-MAP, 2012). The population growth is not homogeneous, in the North the population stabilizes in some decades, in the south there's a strong population explosion (Hervieu & Lacirignola, 2007). The expected average growth rate per year in the coastal fringe (1995 to 2025) is 0,7 % with a minimum value of 0,03% per year in Greece and a maximum of 1,5 % per year in Lebanon and Egypt from (Plan Bleu, 2002). According to the Critical Ecosystem Partnership Fund (CPEF website, 2013) more than half of the total population for the Mediterranean Basin is accounted for by just four countries: Egypt, France, Italy and Turkey. The Mediterranean region is densely populated with relevant differences between highly populated countries like Israel (345 people/Km2), Lebanon (373 people/Km2) and Malta (1,310 people/Km2) and less populated like Algeria (15 people/Km2) and Libya (4 people/Km2)[4]. The increase of population is related with economic development and related urbanization. The human development index has continuosly progressed in the Mediterranean countries since 1980. With an average HDI of 0.767 in 2012, the Mediterranean region was above the world average of 0.694 (CPEF website, 2013). The prerogative of coastal zones to attract economic activities, households and other activities from the inland has been defined by scientific literature as "Littoralization". The concept of littoralization has emerged within the geographical science and "*It has been understood as a process of inhabiting coastal areas*" (Fredotovic & Simunovic, 2006). The highest rates of littoralization in coastal areas are in the southern Mediterranean Basin countries of Jordan (3.1 %), Algeria (2.5 %), Libya (2.2 %) and Turkey (2 %) posing considerable risks to biodiversity (CPEF website, 2013).

The fast population growth and intensive human activities in the Mediterranean coastal regions produce the following effects on coastal zones:

- Housing development
- Land use conflicts
- Legal conflicts (access rights and conservation)

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[4] CEPF - http://www.cepf.net/where_we_work/regions/europe_central_asia/mediterranean/EcosystemProfile/Pages/socioeconomic_context.aspx (accesseed August 10, 2014)

- Lack of long-term strategies for conservation
- Poor understanding of the value of ecosystem services

The growth of population on coastal strip, exacerbate the existing hazards and in particular coastal erosion (e.g. new construction and reduction of buffer ecosystems) and saltwater intrusion with the increase of groundwater demand. These pressures must be taken into account in coastal vulnerability assessment as well as pressures generated by climate drivers. The interaction between climate and non-climate pressure should also be evaluated.

2.4.2 Tourism development

Tourism development is an important human-induced driver of change for the Mediterranean basin. The Mediterranean is chosen by one tourist out of three, representing as a whole the first tourism destination in the world (Satta, 2004). The Mediterranean consists of 29 tourist destinations in Europe, Middle East and Africa, sharing a similar climate, geography, and in most cases a Mediterranean coastline, as well as historical and cultural links dating back to antiquity (Pierret, 2012). Thanks to its unique combination of mild climate, rich history and culture, exceptional natural resources and proximity to major source markets, the group of 29 countries around the Mediterranean Sea is the world’s leading tourism destination in terms of both international and domestic tourism (Pierret, 2012). In the 60's, in the northern Europe an increase in the quality of the life occurred, the coincidence with other factors like paid holidays, the reduction of working hours and increase in the rapidity of mass transportation generated an explosion of tourism in the Mediterranean (Satta, 2004). The three key words for the tourism in the Mediterranean were for a long time: Sun, Sand and Sea, because the climate conditions in the Mediterranean region represent the main factor attraction for tourists from all over the word. If trends from 1990 continue, the Mediterranean Travel Association (META) predicts a more equitable balance in the number of tourist arrivals between the northern and the southern shores of the Mediterranean after 2015. This conclusion was reached following analysis of several quantitative variables collected from UNWTO, WTTC, IMF and country sources (Lamquar, 2012).

In the last decades, the coastal zones of the Mediterranean have been exposed to an increasing pressure, that is not distributed uniformly and as a matter of fact the higher concentration is in the north during the summer months (Satta, 2004). The principal impacts due to tourism are on water resources, local resources, air pollution and noise, solid waste and littering, sewage and groundwater pollution, seawater pollution and biodiversity (Satta, 2004). In the coastal areas the constructions of infrastructures like hotels, marinas, and recreation structures like golf courses, water sports, are the main causes of tourism impacts, because these activities generate pressure on natural resources and coastal landscapes. The use of land for accommodation and other infrastructures and the use of building materials generate impact on renewable and non-renewable natural resources. The coastal zones are exposed to different direct impacts generated by tourism activities like erosion, over exploitation of groundwater and artificialization of natural ecosystems (Satta, 2004). A strong tourism pressures threaten attractive coastal sites, especially in summer, generating, for example, severe damages at the Posidonia sea grass (Satta, 2004).

2.5 The coastal assets at risk

The first step for a local planner, when evaluating the impacts of coastal hazards, is to understand the elements of the coast exposed to risk. We define these elements at risk coastal assets (Lummen et *al.*, 2014). The scope may vary depending on factors such as hazard, size and complexity of the local government, datasets availability and financial resources available (Florida Sea Grant, 2013). The choice of risk assessment targets is first of all related to the identified pressures on the studied coastal zone and then to the issues defined in the scoping phase of the project (Downing & Patwardhan, 2002).

The risk assessment target can be people, natural resources or economic activities. Downing and Patwardhan (2002) introduce the concept of “vulnerable livelihoods” that can be used as a unit for risk assessment as in Figure 2.3.

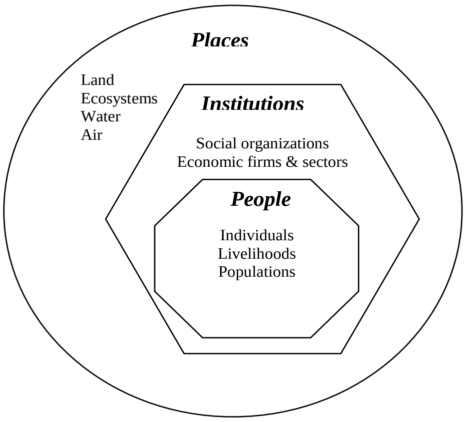

Figure 2.3 Units of analysis for a risk assessment. (Source: Downing and Patwardhan, 2002)

The central objectives of the research remains the identification of a coastal risk assessment tool enabling local governments to develop a primary analysis of climate and non climate forcing and related impacts on coastal zones even with incomplete datasets, minimal staff and limited resources. This research includes physical, socio- economic and ecological targets. We present how the main ecological, social, cultural, and economic assets are exposed to coastal hazards risk.

2.5.1 The ecological assets

Biodiversity and ecosystems

As we have seen in the previous paragraph, the SLR accelerates some impacts such as coastal erosion, flooding and saline intrusion. The loss of coastal land such as beaches, dune systems and wetlands brings with it the loss of biodiversity. In the Mediterranean, the spontaneous resilience of coastal ecosystems to adapt to natural change is dramatically reduced by the loss of natural land. The rapid urbanization of the coastal strip has, in fact, compromised the ability to migrate into the interior of these ecosystems. Other human drivers are very important, such as the river flow regulation and the construction of dams that have a negative impact on the supply of sediment to the sea contributing to coastal erosion.

As reported by WG2 of IPCC (2007) coastal vegetated wetlands are sensitive to SLR as their location is strictly related to sea level. SLR can directly affect coastal endemic and habitat-forming species and recent findings strongly suggest that sea grass, (i.e. Posidonia) could be affected by sea warming and is highly sensitive to storm extreme events (IUCN, 2012).

Acidification

The Mediterranean Sea is a semi-enclosed body of water with high environmental variability that like other oceans by ocean acidification (Geri et *al.*, 2014). Acidification is the term used to describe the on-going decrease in sea pH caused by human CO2 emissions.

Interesting outcomes derive from the project MedSeA[5], financed by the FP7, which aims to assess uncertainties, risks and thresholds related to Mediterranean acidification at organismal, ecosystem and economical scales.

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[5] MedSeA - http://medsea-project.eu (accessed August 1, 2014)

2.5.2 The physic-environmental assets

Water supply

Sea Level Rise is expected to exacerbate existing problems concerning water supply in several Mediterranean countries, ad especially small islands, and cause a decline in water quality through increased salt-water intrusion in coastal aquifers (Karas, 1997). The most vulnerable areas in the Mediterranean for water availability are the eastern countries. As reported by Hoff (2013), water availability for a medium climate change scenario (SRES A1B), in the eastern Mediterranean, is projected to be reduced by about 30% by 2050.

An example is in Malta. The Maltese islands are poorly endowed with freshwater, and they present a very high population density associated with high tourism pressure. The saltwater desalination is an important component of the drinking- water supply since the 80s. The over-exploitation of aquifers and the saltwater intrusion resulted in groundwater depletion (quantity and quality) (FAO, 2006).

Infrastructures and housing

Inundation related to accelerated SLR may increase the risk of infrastructure damage as well as the flooding of roads, railways, houses and storms may provoke impacts on maritime transport and ports (Travers, 2010). El-Raey (1999) produced a vulnerability assessment of the Governorate of Alessandria in Egypt to the impacts of sea level rise, which concluded: “if no action is taken, an area of about 30% of the city will be lost due to inundation.

Almost 2 million people will have to abandon their homeland; 195,000 jobs will be lost, and economic loss of over $3.5 Billion is expected over the next century” (El-Raey, 1999).

2.5.3 The socio-cultural assets

Cultural heritage

SLR and coastal erosion will generate loss of coastal land where are located important cultural heritage. A recent research of Marzeion and Levermann (2014) has evaluated the UNESCO cultural heritage at risk along the world’s coastal areas.

To determine the impact on UNESCO cultural world heritage sites, we use data on location and spatial extent of each site that is classified either as cultural or mixed (i.e., both of cultural and natural significance) in the UNESCO list.

Figure 2.4 Location of UNESCO cultural world heritage sites impacted by sea level rise in Europe and in the Mediterranean. Colours: uncertainty of the lowest ΔT at which the site will be below local sea level. Black circles: sites which are impacted already at the present day ΔT = 0.8 K. (Source: Marzeion & Levermann, 2014**)**

2.5.4 The economic assets

Agriculture

For the particular morphology of the basin, agricultural activities take place in the limited lowlands lying between the rocky coastal regions of the Mediterranean Sea that are somewhere the result of the reclamation of wetlands. The changing of coastal areas, especially in terms of coastal erosion and saltwater intrusion, has a dramatic impact on agriculture economy. Estimates indicate that the costs of climate change impacts (e.g. SLR combined with precipitation and droughts) for some agricultural countries (Syria, Egypt, Morocco, and Tunisia) can range between 2% and 9% of the countries' agricultural GDP by 2050 (Ferragina & Quagliarotti, 2008).

Fishing

Climate change has a direct influence on planktonic communities composition and their distribution patterns. Variation in patterns of plankton abundance and distribution may determine negative effects on the ecosystem functioning (UNEP-MAP, 2010). Sea level rise may impact directly on coastal fisheries communities (e.g. facilities and infrastructures) and on ecosystems such as sea grass and coral reefs, which have a crucial role for fisheries. Mediterranean fish resources are in an overexploitation (i.e. overfishing). In synergy with variations in water masses' circulation, overfishing may give rise to severe consequences for population dynamics of several fish species (UNEP-MAP, 2010).

Tourism

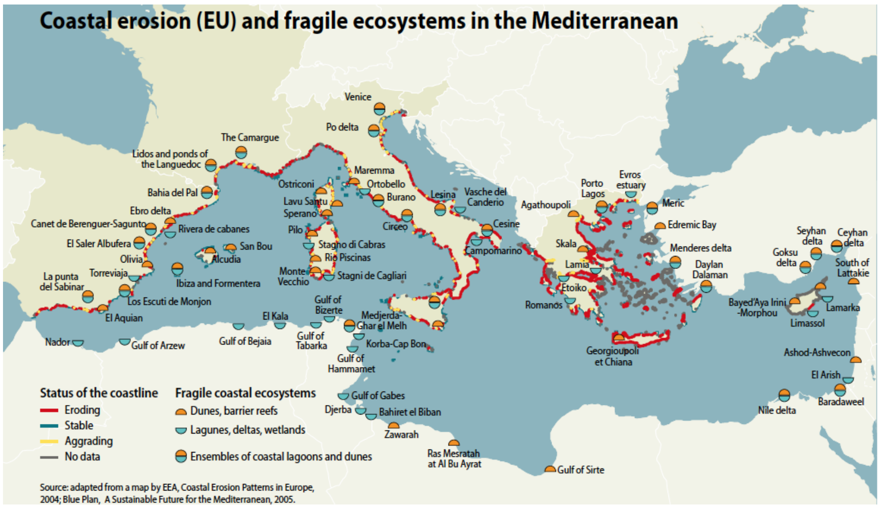
The sprawl of tourist resorts and related infrastructures makes tourism development one of the principal drivers of environmental impacts in the Mediterranean: disappearance of dunes, coastal marshes and sea grass, contamination of water by recreational craft, land use and consumption of water resources (WWF, 2004). Nevertheless tourism economy is already experiencing the negative effects of climate change. Problems of water supply due to saltwater intrusion are becoming increasingly common in Mediterranean tourist areas especially in islands aquifers (Custodio, 2012). Coastal tourism will also be affected by accelerated coastal erosion and changes in the marine environment and marine water quality, with less fish and a more frequent jellyfish and algae blooms (Hester & Harrison, 2011).

2.6 Coastal hazards

Coastal zones are the interface between land and sea and represent one of the most dynamic and complex systems in nature. The change in properties of land and sea will have significant physical and socio-economic impacts (Ozyurt, 2007). Coastal zones are constantly under stress from land-based sources (e.g. river flooding) or sea-based sources (e.g. waves and storm surges). This research will focus mainly on the following natural hazards generated by marine sources: coastal erosion, coastal flooding, and salt water intrusion. The main effects of SLR and Storms on coastal zones are increased coastal erosion, increased flooding and salinization of groundwater (IPCC SPM and WGII Ch. 5, 2014). The aspect that requires attention concerns the ways SLR and Storms forcing increases the effects of the current natural hazards such as coastal erosion, flooding, and salt-water intrusion. In particular accelerated SLR can intensify these hazards like for example saltwater intrusion (Ozyurt, 2007; Snoussi et *al.*, 2008). Furthermore non-climate forcing like tourism development can accelerate natural hazards like coastal erosion and saltwater intrusion this last with an over exploitation of groundwater resources generating in increasing of saltwedge intrusion. In this sense it is important to understand how climate and non-climate forcing influence coastal hazards. The consequences of climate and non-climate changes will have a direct effect on both ecological and socio-economic systems of Mediterranean coastal regions. In particular, the low-lying coastal areas and islands, will be more exposed to flooding, erosion and saltwater intrusion. The most common coastal hazards affecting Mediterranean coastal regions are presented below in detail.

2.6.1 Coastal erosion

Around 46 % of the Mediterranean coastline is characterized by low-lying sedimentary coasts including beaches, dunes, reefs, lagoons, estuaries and deltas that are more dynamic than rocky coasts because the balance between sea forcing and sediment supply will determine whether the coastline advances (accretion), remains stable, or retreats (erosion) (UNEP-MAP, 2012). Furthermore, the stability of coastline is affected by the increase in the artificialization of coastal zones. According to EEA[6], 25% of the Northern Mediterranean coastline is affected by erosion and sea defences are present along 10% of the European side of the Mediterranean coastline has showed in the Figure 2.3 (UNEP-MAP, 2012). Data are not updated and they refer to 2004.


Coastal erosion (EU) and fragile ecosystems in the Mediterranean

Source: adapted from a map by EEA, Coastal Erosion Patterns in Europe, 2004; Blue Plan, A Sustainable Future for the Mediterranean, 2005.

Figure 2.5 Coastal erosion and fragile ecosystems in the Mediterranean coastal zones. (Source: UNEP-MAP, 2012)

The CORINE coastal data[7], referred to 2004, shows that at the end of the 20th century, 1.500 km of the EU Mediterranean coast had been transformed to “artificial coast”. Considering the acceleration of the coastal urbanization process in the Mediterranean countries in the last years it can be concluded that this value is underestimated nowadays. The increase of coastal erosion due to SLR is one of the main reasons of coastal land loss. The coastal erosion depends by waves and currents action and coastal type (e.g. geomorphology). With a rising in sea level, there will be an acceleration of coastal erosion because, it will generate higher waves and change in current dynamics influencing the sediment budget (Ozyurt, 2007). A further contribution to coastal erosion can result from the “increased frequency of moderate storms” and winds (Sanchez-Arcilla, 2010).

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[6] EEA - http://www.eea.europa.eu/data-and-maps/figures/coastal-erosion-patterns-in-europe (accessed August 1, 2014)

[7] CORINE - http://www.eea.europa.eu/data-and-maps/figures/coastal-erosion-patterns-in-europe-2004 (accessed February 10, 2014)

The main scientific question regards how to correlate SLR to coastal erosion and in particular how shoreline responds to the rising of sea level. The scientific literature from the 60s (until today) made primarily appeal to a concept known as "Bruun Rule". The so-called “Bruun Rule” is a simple two-dimensional model of shoreline response to rising sea level. The success of this model is mainly due to its ease of application, the difficulty of determining the actual evidence of its validity or non-validity, its application by the scientist without a critical approach and finally the lack of viable alternatives (Cooper & Pilkey, 2004). Undoubtedly, the simplification of the formulas of the "Bruun Rule" has greatly influenced the belief by policy makers that this concept can offer a prediction of future shoreline position under an accelerated sea-level rise scenario. What emerges from the literature on coastal management and adaptation to SLR, is that research has focused more on the need to establish the best mitigation measures to coastal erosion than to call into question the simplifications proposed by the Bruun Rule. Nevertheless some scholars have addressed the issue of the limits of the Bruun Rule and the need to abandon this concept, according to Cooper and Pilkey (2004) the Bruun Rule “*has no power for predicting shoreline behaviour under rising sea level*" while according to Rollason et al. (2010) the Bruun Rule "*is not able to account for regional long shore transport and wave climate interactions with headlands, breakwaters and other structural features of the coastline in predicting recession two to sea level rise*". More recent models like the PCR model, a process based probabilistic model to derive estimates of SLR driven coastal recession, have been developed. The authors suggest PCR as “*a more appropriate and defensible method*” for the definition of coastal erosion due to SLR than the Bruun Rule (Ranasinghe et *al.*, 2011). In their analysis of SLR and shoreline responses modelling, Canezave and Le Cozannet (2013) highlight that the preferring option to evaluate impacts of SLR on shoreline behaviour is to model hydro-meteorological, biological and geodynamic processes in combination with human actions keeping in mind that these processes “*are interacting non-linearly on different spatio-temporal scales*” (Canezave & Le Cozannet, 2013). In this respect further research is needed to disentangle the consequences of SLR on coastal zones to support coastal managers and practitioners to define realistic adaptation scenarios to sea level changes (Katsman et *al.*, 2011; Canezave & Le Cozannet, 2013).

IPCC estimates direct costs from sea level rise in the EU27 without adaptation to €17 billion per year by 2100 (IPCC, 2014b) and states that “*1 m sea level rise in Turkey could affect 3 million additional people and put US$12 billion capital value at risk, with around US$20 billion adaptation costs*” (IPCC, 2014b).

2.6.2 Coastal Flooding

Along the Mediterranean coast, there's a strong risk for low-lying coastal areas associated to extreme sea levels. These extreme events frequently cause coastal flooding, which cause negatively impact on infrastructures, environment and population that live in the coast. Coastal flooding generated by storm surge and wave-breaking represents one of the main destructive natural disasters in the Mediterranean (Sanchez- Arcilla et al, 2010).

The main causes that generated coastal flooding are a combination of high water levels (caused by tides and storm surge) and waves (with a overtopping of coastal defences or an inundation of low-lying areas) (Wolf, 2009). Waves and storm are the consequence of high wind events that in combination with river flow inundation and precipitation can increase the sea level and the coastal flooding (Wolf, 2009). Non-climatic forcing like undersea earthquakes (tsunami), landslides, volcanic eruption and meteorites, can also generate coastal flooding (Wolf, 2009).

In the Mediterranean region the first dangerous meteorological hazard are floods; the second and the third are windstorms and hail. This is related to high flood frequency, but also to the coastal vulnerability due to human activities. For example, in Spain, southern France, Italy and the west of the Balkan Peninsula, the high frequency of floods makes that this events is considered a component of the local climate (Llasat et *al.*, 2010). The increase in frequency and intensity of extreme events like floods due to climate change (e.g. SLR and storm surges) would result in different impacts on population, freshwater availability and quality, the food production and moreover would increase the risk of infectious diseases, above all in Mediterranean developing countries (Sanchez-Arcilla et *al.*, 2010). Along the Mediterranean coast, the countries with risk of coastal flooding are Spain, Italy, Greece, Croatia, Albania, Turkey and Syria. For example, in Italy, coastal flooding might be frequent and distributed along the coast and the areas at risk of sea flooding are 4.500 square kilometres (MELS, 2007). During this century and beyond an increase in flooding frequencies is expected, due to a combination of wind forcing associated to anthropogenic global warming (Sanchez-Arcilla et *al.*, 2010). The vulnerability of population and ecosystems that live in coastal regions can increase due to the interaction between different of climate forcing like SLR and Marine storms enhancing the existing impacts like coastal flooding, erosion and salt water intrusion in the aquifers. An example is the Ebro region, where occur simultaneously eastern wave storm and SLR for the passage of low-pressure systems off the delta, this combination, creates the inundation of agricultural zones and the affectation of natural values due to flooding (Sanchez-Arcilla et *al.*, 2010). The zones along the coast with low-lying coastal areas, high population density and with small tidal range are more vulnerable to SLR and consequently to coastal flooding, the latter can influence the population that live in the coastal countries; every year, in the

Mediterranean an additional 1.6 million people might suffer the experience of coastal flooding by 2080 (Alcamo et *al.*, 2007). In the 21th century, the relationship between flooding and number of people will change due to different causes, including change in flood level, human exposure to flooding and the standard of flood management infrastructure (Nicholls, 2004). In the 2080s, if no adaptation is taken, coastal flooding is very likely to affect an additional 775,000 and 5.5 million people per year in the EU27 (IPCC, 2014b).

2.6.3 Saltwater intrusion

The acceleration of urbanization in the last decades has increased the consumption of groundwater reserves of Mediterranean coastal regions. Over-abstraction from coastal aquifers has led to the movement of seawater toward aquifers and increased the salinity of groundwater. The aquifer contacts the sea at the shoreline or seaward, the freshwater that is less dense than seawater, floats as a lens-shaped layer on top of seawater (Fig. 2.6), and the weight of the overlying freshwater depresses the seawater below sea level.

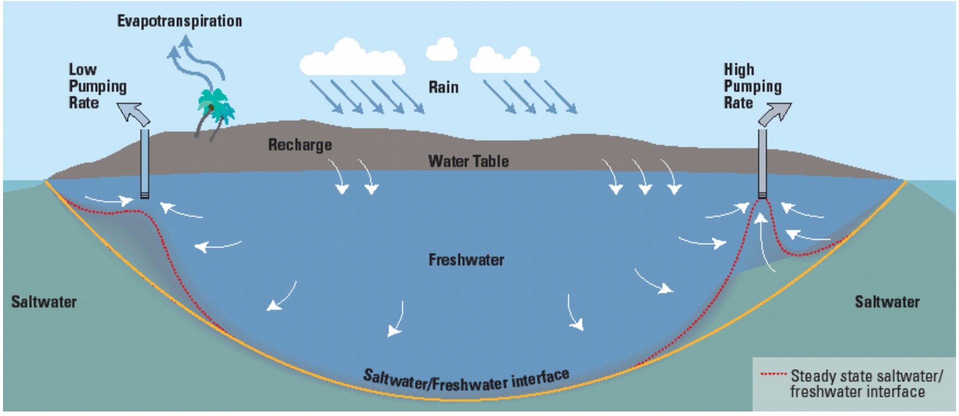

Figure 2.6 Unconfined aquifer in the case of an island.

The first physical formulation of seawater intrusion was made by Badon Ghyben (1889) and Herzberg (1901), thus called the Ghyben-Herzberg relation. According to the Ghyben-Herzberg relation, seawater intrusion occurs because freshwater is slightly less dense than seawater (1.000 g/cm3 versus 1.025 g/cm3). This theory assumes two fluids separated by a sharp interface (Figure 2.5) and ignores complexities of real aquifers (e.g. the transition zone). The Ghyben-Herzberg relation can be used to determine the shape and position of the sharp interface under static equilibrium conditions (Sherif and Singh, 1999). The principle assumes that the equilibrium condition exists between the seawater offshore and a freshwater flowing from the upland area down toward the ocean. Figure 2.7 shows the equilibrium interface assumed in the Ghyben-Herzberg relation.

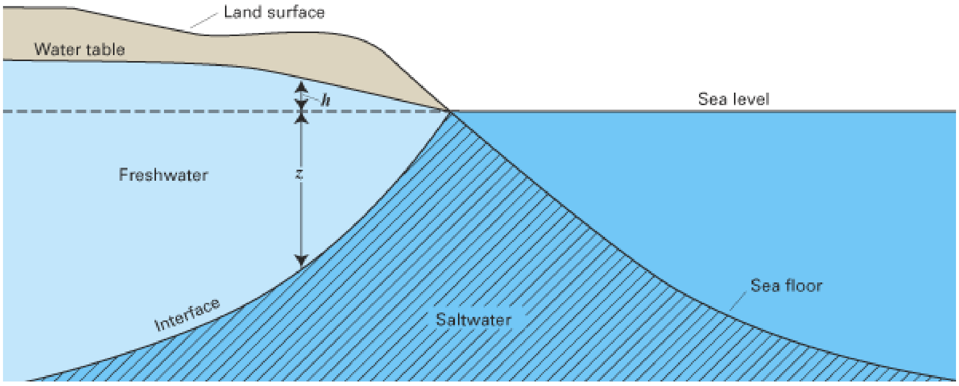

Figure 2.7 Equilibrium in the interface between freshwater and seawater.

In the equation,

$$z = \frac{\rho_f}{(\rho_s - \rho_f)} h$$

The thickness of the freshwater zone above sea level is represented as h and that below sea level is represented as z. The two thicknesses h and z, are related by ρf and ρs where ρf is the density of freshwater and ρs is the density of seawater. As already mentioned, freshwater has a density of about 1.000 g/cm3 at 20 °C, whereas that of seawater is about 1.025 g/cm3. The equation can be simplified to $z \ = 40h$, through the simplified equation we find that the slope of the sharp interface is 40 times greater than that of the water table. If the water table drops 10 cm, the interface will rise at 4 m.

Under conditions of climate change, the rate of SLR is sufficiently slow so that groundwater heads at and in the vicinity of the coast will increase in parallel rather than remaining at their present position. If the sea level rises, the separation between freshwater and seawater will move sideways to the ground and level piezometric groundwater will be enhanced (Fig. 2.7). Thus, this will result in a reduction in the volume of fresh groundwater through the salt wedge intrusion. The hydrogeology of low areas, often composed of alluvial sedimentary permeable soil can be changed. The aquifers at risk of a rise of the same order as that of sea level would have considerable impact on vegetation and even at ultra-high elevations. Deep coastal aquifers with mild hydraulic gradients are more vulnerable under conditions of climate change and SLR. As sea levels rise, the seawater could be able to overcome natural barriers to move into low-lying areas now dominated by freshwater. Rising sea levels will also push seawater into coastal fresh water aquifers. While this impact may not be noticed on the surface it could affect groundwater that seeps into estuaries.

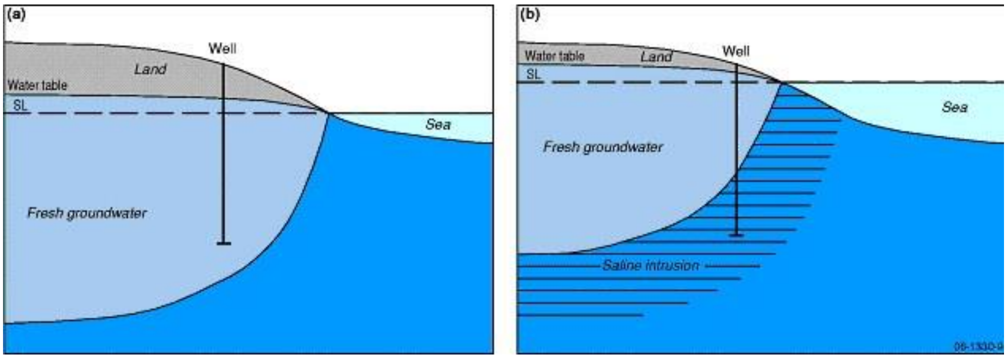

Figure 2.8 Seawater-freshwater interface in: (a) an unconfined (hypothetical) coastal aquifer; and (b) the same aquifer under a sea-level rise scenario.

The Ghyben-Herzberg relation is based on the sharp interface assumption, which is not realistic especially when the width of the dispersion zone is large. The width of the dispersion zone may vary from a few meters to several tens of kilometres, as, for example, in the case of the Nile Delta aquifer (Sherif, 1999). The process of seawater intrusion depends on many hydraulic, geometric and transport parameters. Each aquifer has its conditions, and the sharp interface approach cannot be applied. Quantitative prediction of the expected seawater intrusion can only be evaluated through numerical models, which account for the dispersion zone. SLR will cause seawater intrusion into coastal aquifers, particularly in regions of high groundwater withdrawal. For the populations of small islands, reduction or disappearance of potable water may be the greatest impact on their survival, rivaling in importance both coastal erosion and lowland flooding (FitzGerald, 2008). Entire island nations (e.g. Tuvalu, Marshall Islands, etc.) are already being affected by seawater intrusion (Roy & Connell, 1991). SLR could enhance as well seawater intrusion along the Mediterranean Sea's constricted basin. This basin has 45,000km of coastline with numerous deltaic and estuarine areas in which a multitude of natural resources, such as underground freshwater could be threatened (Verger, 2000). Almost all the models developed to simulate and control seawater intrusion do not consider the effects of climate change and SLR in the simulation process. Just few researchers have considered the effects of climate change and SLR on seawater intrusion. An extensive overview is proposed by Abd-Elhamid (2010). EL Raey (1999) carried out an assessment of vulnerability and expected socioeconomic losses in the Nile Delta coasts due to the impact of SLR of 50 cm by 2100, in particular in Alexandria, Port Said, Egypt. Sherif and Singh (1999) investigated the effects of likely climate change on seawater intrusion in the Nile Delta aquifer, Egypt, and Madras aquifer, India. The study found that seawater intrusion is vulnerable to climate change and SLR.

2.7 Mediterranean coastal vulnerability “hotspots”

As reported by the Fourth Assessment Report (IPCC, 2007) and highlighted by the CIRCE project (Navarra & Tubiana, 2013) the Mediterranean is considered itself a “hot spot” for climate change. A first report on Mediterranean hotspots (e.g. deltas, lagoons, tidelands and some islands) in terms of coastal vulnerability to climate change is the one prepared by UNEP & EEA (1999) largely confirmed by Plan Bleu reports on the State of the Mediterranean coastal and marine environment (UNEP-MAP, 2009 and 2012) and by the case studies of the CIRCE project (Navarra & Tubiana, 2013). In the CIRCE project, eleven-location case studies were selected to represent three Mediterranean environments: coastal, rural and urban. Every case study represents a unique set of climate issues and reflects the east- west and north- south contrasts. These case studies allow the identification of information for the entire Mediterranean region, so they represent the entire region. A non-exhaustive list of coastal hotspots to sea level rise is reported in Table 2.5 with a description of main potential impacts.

Coastal “hotspots”	Major potential impacts	Source
Cres-Lolinj, Croatia	Increased salinization of lake Vrana; extension of thetourist season; increased risk from forest fires.	UNEP & EEA 1999, Baric et al. 2008
Kaštela Bay, Croatia	Inundation of Pantana spring and Zrnovica estuary; increased salinization of estuaries and groundwater; negative impact on coastal services and infrastructure; accelerated deterioration of historic buildings; increase in domestic, industrial and agricultural water requirements.	UNEP & EEA 1999, Baric et al. 2008
Delta of Rhône, France	Erosion of unstable or threatened parts of coastline; reduction of wetlands and agricultural land; increased impact of waves; increased salinization of coastal lakes; destabilization of dunes; intensified tourism.	UNEP & EEA 1999, Tol et al.2006
Island of Rhodes, Greece	Increased coastal erosion; salinization of aquifers; increased soil erosion Maltese Islands, Malta salinization of aquifers; increased soil erosion; loss of fresh-water habitats; increased risk for human health, livestock and crops from pathogens and pests.	UNEP & EEA, 1999, IEEP 2013
Thermaikos Gulf, Greece	Inundation of coastal lowlands; saline water penetration in rivers; drowning of marshland; increased sea water stratification and bottom anoxia; decreased river runoff; salinization of ground water; decreased soil fertility; damage to coastal protective structures; extension of thetourist season.	UNEP & EEA, 1999, Poulos et al. 2009
Delta of Po, Italy	Increased flooding and high-water events; increased coastal erosion; retreat of dunes; damage to coastal infrastructure; salinization of soils; alteration to seasonal water discharge regimes; reduced near-shore water mixing and primary production; increased bottom water anoxia.	UNEP & EEA 1999, Torresan et al. 2012
Delta of Ebro, Spain	Increased coastal erosion; reshaping of coastline; loss and flooding of wetlands; reduced fisheries yield.	UNEP & EEA 1999, Sánchez-Arcilla et al. 2008

Gulf of Valencia, Spain	Marine environment (sea level, wave storms and surges, and sea-water temperature), vulnerability of coastal zones to erosion, flooding and saline intrusion, marine pollution, biodiversity and invasive species, and the corresponding impacts on fisheries and industry (including tourism)	Navarra & Tubiana, 2013
Albanian coast, Albania	Even if there are significant uncertainties regarding projections of sea level rise at the Albania coast, due to local processes such as land subsidence and uplift the following impacts already occur: salinization of coastal aquifers and shortage of adequate quality of drinking water; soil erosion (physical); extension of summer drought; extension of the tourist season.	UNEP & EEA 1999, World Bank 2009
Gulf of Oran, Algeria	Vulnerability of coastal zones to erosion, flooding and saline intrusion (freshwater aquifers vulnerable to inundation). Alien jelly fish species pose a threat to numerous native Mediterranean species in the Gulf of Oran.	CIRCE, 2013
Delta of Nile, Egypt	Increased coastal erosion; overtopping of coastal defenses and increased flooding; damage to port and city infrastructure; retreat of barrier dunes; decreased soil moisture; increased soil and lagoon water salinity; decreased fisheries production.	El Raey et al. 1999, UNEP & EEA 1999, Frihy 2003, Hereher 2010, Hassaan & Abdrabo 2013
Fuka-Matrouh, Egypt	Increased evapotranspiration and decreased rainfall; extension of summer aridity; increased coastal erosion; flooding in the eastern part; decreased soil fertility.	UNEP & EEA 1999, Yousif & Bubenzer 2011
Ichkeul-Bizerte, Tunisia	Increased evapotranspiration leading to decreased soil moisture, reduced lake fertility and enhanced salinity; increased salinity of the lakes and shift to marine fish fauna; reduced extent of wetlands and loss of habitat.	UNEP & EEA, 1999
Gulf of Gabes, Tunisia	Salinization of ground water, coastal erosion. The Island of Kerkennah and the four islands, Kneiss could be inundated by water in pessimistic SLR scenarios (CIRCE, 2013)	Navarra & Tubiana, 2013, Gzam et al 2013
Sfax coastal area, Tunisia	The mean sea level at the port of Sfax has augmented by a mean value of 17 cm during 60 years between the first and last collected data,(1946 and 2006) to reach a value of 116 cm, indicating an annual increase of 2.8±0.2mm/year. Major impacts are salinization of ground water; erosion and potential flooding.	UNEP & EEA 1999, Saidani 2007
Syrian coast, Syria	Increased soil erosion; increased salinization of aquifers; erosion of beaches and damage to coastal structures and human settlements due to exceptional storm surges.	UNEP & EEA 1999

Table 2. 5. Mediterranean coastal hotspots.

This analysis confirm that the most relevant hazard happening in the Mediterranean coastal hotspots to Climate variability are erosion, flooding and saltwater intrusion.

2.8 Summary

The Mediterranean coastal areas are very vulnerable to climate change and their impacts and especially to SLR and Storms. The interaction between SLR and Storms can produce several physical effects, like storm surges affecting coastal systems and low-lying areas. Storm surges and extreme waves must necessarily be accounted for when planning coastal defences. Surges and waves are responsible for the evolution of the coastline, they are a recurrent cause of damages, and they have, in general, a substantial impact on the marine and coastal ecosystems (Lionello et *al*., 2010).

The CIRCE projections (Gualdi et *al*., 2013) provide an estimate of the possible sea-level change in the Mediterranean considering only the steric effect. In CIRCE simulations, the 2021–2050 mean steric sea level, compared to the reference period (1961–1990), is expected to rise in the range between +6.57 and +11.56 cm (Gualdi et *al*., 2013). Existing studies show a small effect of climate change and “suggest weaker marine storms in future scenarios than in the present climate” (Gualdi et al., 2013).

The preparation of a correct coastal vulnerability assessment needs to take into consideration also non-climate forcing (e.g. population growth and tourism development) and the evaluation of the interactions between climate and non-climate forcing.

This research focus on the sea-related forcing like SLR and Storms combined with non-climate forcing and their effects on the most common natural hazards: coastal erosion, coastal flooding and saltwater intrusion. Changes in precipitation and winds forcing are not directly considered as a climate forcing to coastal zones for this research. Nevertheless precipitation is considered as a direct contributor of the Total Water Level affecting the shorelines.

Another determining factor in the risk assessment is the definition of coastal assets intended as exposure. For an integrated assessment of coastal risk, ecological, physical, environmental, socio-cultural and economic assets should be considered in the analysis.

In the coastal regions of the Mediterranean several hotspots exist, and these are a more concentrated in the southern and eastern shores.

CHAPTER 3. VULNERABILITY AND RISK CONCEPTUAL FRAMEWORK

3.1 Introduction

n the research community there are two main streams to approach the concept of vulnerability and risk and associated methods to their assessment (Romieu et al., 2010). These two research streams can be defined as a "disaster risk reduction" community and the "climate change adaptation" community (Giupponi, 2013). The mains sources of divergence must be found in the initial difference of purpose, the first being disaster risk reduction measures and the second climate change adaptation strategies (Romieu et al., 2010).

With the aim of translating the conceptual definition of “risk” into “risk assessment" methodology, the main findings of disaster risk reduction (DRR) and climate change adaptation (CCA) approaches are explored.

The choice of the methodological approach needs to take into account the questions posed at the base of the research. On the one hand, the DRR approach focuses on the identification of measures to reduce the risk and decrease the probability of occurrence of damage to the system while the CCA approach focuses on adaptation planning. In fact, both aspects are relevant although with different intensities. One of the main objectives of this research is to define the best strategy to adapt to the coastal areas subject to climate stressors and incorporate it into coastal planning and management. Nevertheless, within the overall adaptation policy, is of fundamental importance also to define specific measures to reduce the risk for local communities, infrastructures and coastal ecosystems.

This chapter intends to provide a conceptual framework behind the construction of a risk assessment methodology for the Mediterranean coastal area.

3.2 Conceptual framework for vulnerability and risk in the scientific community

3.2.1 Evolution of vulnerability and risk concepts

It is not the scope of this research to report the enormous amount of scientific literature concerning the concept of "risk" related to climate change and neither to review all the definitions of "vulnerability and "risk". For the discussion of definitions the reader is directed to Brooks (2003), Cutter (2009) and Fussel (2009). Nevertheless the development of a methodology for the assessment of coastal vulnerability and risk makes necessary the definition of a theoretical framework around theses concepts. The first consideration is the fact to emphasize that the concept of risk emerges in relation to a particular system subjected to a specific hazard. In this research, we refer to the coastal areas as a "system" and to the natural hazard related to the physical effects of climate and non-climate changes. In practical terms, this study intends to focus on the concept of coastal risk highlighting the not always easy clear overlay and confusion around the definitions of vulnerability and risk.

Reviews of the interpretations of ‘vulnerability' in climate change research have identified two different concepts and two different research streams designated as Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA). Various authors (Burton, 2002; O’Brien et al., 2004; Fussel, 2005; Romieu et al., 2010; Wolf, 2012; Giupponi et al., 2013) have investigated differences and similarities. Smit (1999) and Burton (2002) have identified two types of vulnerability concepts and explained differences but for a more detailed discussion on these two approaches the reader is directed to O’Brien (2004) and Fussel (2005)

According to the Coastal Zone Management Sub-Group (1992) coastal vulnerability, can be defined as the nation's ability to cope with the consequences of the coastal hazard (Cambers, 2001). In other terms, coastal vulnerability can represent the resources at risk from coastal hazards (Cambers, 2001). Coastal hazard may be defined as the occurrence of a phenomenon (e.g. storm surge), which has the potential for causing damage to, or loss of, natural ecosystems, buildings, and infrastructure (Cambers, 2001).

In the DRR scientific literature, a first definition of vulnerability was proposed by Blaikie et al. (1994) as “the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard". This definition has a direct implication in building the vulnerability assessment process because vulnerability is defined as the capacity to respond to specific natural hazard stress (Olmos, 2001).

In the CCA scientific research, the definition of vulnerability must be referred to the IPCC’s AR4 work. According to the WGII of IPCC published in AR4, vulnerability is “the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity” (IPCC, 2007). In other terms vulnerability (IPCC, 2007) is a function of the three terms, and it can be denoted as Vulnerability = f (Exposure, Sensitivity, Adaptive Capacity), where:

- **Exposure** defines the nature and amount to which the system is exposed to climate change phenomena;
- **Sensitivity** reflects the system's potential to be affected by changes. Sensitivity can also be defined as the biophysical effect of climate change (i.e. SLR) that can be altered by socio-economic changes[8];
- **Adaptive capacity** describes the system's capacity to adapt to changes. Smit et al. (2001), have identified seven factors that determine adaptive capacity: Wealth, Technology, Education, Institutions, Information, Infrastructure and Social capital.

The first two attributes, exposure and sensitivity, are part of the system (or community) and depend on the interaction between the characteristics of the system and the characteristics of the climate changes (Smit & Wandel, 2006). Adaptive capacity can be defined as the ability of a system to change in a way that makes it better equipped to manage its exposure and/or sensitivity to a climatic stimulus (Preston & Stafford-Smith, 2009). Adaptive capacity is context-specific and varies among countries, communities, social groups, and individuals and over time (Smit and Wandel, 2006) and it remains a difficult concept to define explicitly within vulnerability assessments (Adger & Vincent, 2005). Adaptive capacity in vulnerability assessment scientific literature is often measured in terms of resources availability (Preston & Stafford-Smith, 2009). While exposure or sensitivity are directly related to vulnerability: the greater the exposure or sensitivity, the greater is the vulnerability, adaptive capacity is inversely related to vulnerability: the greater is the adaptive capacity, the lesser is the vulnerability. Therefore, the objective of reducing vulnerability will consist in reducing exposure and sensitivity, and/or increasing adaptive capacity. The conceptual framework (Figure 3.1) proposed by the WGII of IPCC in AR4 (IPCC, 2007) for coastal vulnerability distinguishes between the physical system and the socioeconomic vulnerability and their capacities to cope with the effects of forcing (e.g. Sea Level Rise). In this framework resilience (and resistance) represents the physical system's robustness or ability to continue functioning in the face of possible disturbance. Together, these factors determine the Natural Vulnerability of the coastal zone that can be affected by human activities (IPCC, 2007). The ability to prevent or cope with the impacts of biogeophysical effects of SLR of the Socio-economic system defines the Socioeconomic Vulnerability. The natural and the socioeconomic systems should be considered as inter-dependent systems (IPCC, 2007).

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[8] KNOW CLIMATE OF CONCERN - http://know.climateofconcern.org/index.php?option=com_content&task=article&id=144# (accessed December 28, 2013)

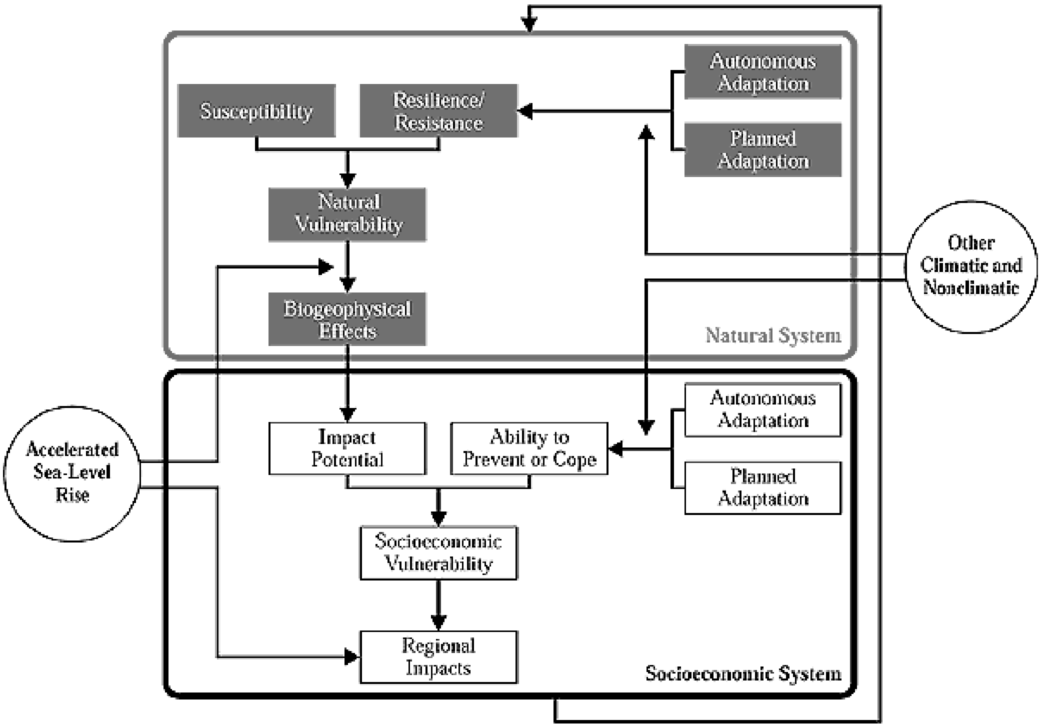

Figure 3.1 Conceptual Framework for Coastal Vulnerability Assessment. (Source: IPCC, 2007)

The vulnerability assessment process begins with an analysis of how the physical system responds to the biophysical effects of changes. This analysis includes the understanding of the physical system susceptibility (exposure, or potential of the system to be affected by hazards), and its natural capacity to cope with hazards, measured by resistance or resilience (sensitivity) (Abuodha & Woodroffe, 2006). The level of vulnerability varies in relation to the changes of natural and socioeconomic systems characteristics within the coastal zone. According to Hinkel and Klein (2006), the level of vulnerability is specific to a given location, sector or group and depends on its physical and socio-economic features. Exposure, sensitivity and adaptive capacity, are dynamic cause they vary over time, by type, from stimulus to stimulus, and they are place and system-specific (Smit & Wandel, 2006).

Temporal dimensions and variability are crucial to coastal zone dynamics if we consider that time scale present can range from hours to days for storm surges, from days to years to tidal ranges and from decades to millennia in the case of regional net land movements (ETC-CCA, 2011). Coastal zones are not in a steady state, but changes across time in response to daily forcing (e.g., tides and precipitation-river flow), seasonal forcing (e.g., climatic patterns), annual forcing (e.g., fisheries yield), and decadal forcing (e.g., ENSO) to glacial-interglacial scales (Crossland & Kremer, 2001).

The main differences of the two approaches are reported in the Table 3.1 adapted from Romieu et *al.* (2010).

Research stream	DRR	CCA
Differences		
Objective pursued	Identify risk reduction measures: reduce the probability of damage	How to face a progressive climate change: adaptation relevance and strategies
Process	Natural hazards—shock	Progressive and irreversible—stress
Timescale	Event-scale (before/during/after), discrete events, static processes	Long-term and progressive viewpoint (e.g. 2100) discrete and continuous, dynamic processes
Spatial scale	From a local consideration to a global one	From a global awareness to local need
Functional scale	Often lies within the responsibility of the Ministry of the Interior, Defence or Development	Mainly environment ministries and meteorological services
Simplified formulation	Risk = Hazard * Exposure * Vulnerability	Vulnerability = Impacts - Adaptation
Vulnerability assessment	Step within the risk assessment End in itself Risk is associated with the notion of probability of occurrence at any time	Prospective scenarios until a given term
Level of uncertainty	Low to medium	Medium to very high
Common issues	Find a convergence between ‘‘impact based’’ and ‘‘human based’’ approaches Take into account dynamics and interactions of the socio-environmental system	

Table 3.1 Synthesis of gaps and common issues between vulnerability in the contexts of climate change and natural hazard. (Source: Romieu et *al*., 2010)

According to Romieu et *al.* (2010,) the main conclusion of the comparison between DRR and CCA approaches "*is that the gaps identified between coastal vulnerability in natural hazards and climate change communities are highly related to the major objectives of both concepts*". The main differences identified by Romieu et *al.* (2010) “*are linked to process (stress vs. shock), scale (temporal, functional and spatial), assessment approach (statistical vs. prospective) and levels of uncertainty*". The common issues between the two approaches, regarding convergence between human-based and impact-based approaches and the need to take into account dynamics and interaction of the socio-environmental system, must be “*addressed in future conceptual and methodological development*” (Romieu et *al.*, 2010).

Regarding this literature review what emerges clearly is that the conceptual framework defined for “vulnerability” defined until now, especially in the CCA stream proposed by IPCC’s AR4 (IPCC, 2007), the concept of risk is missing. Moreover risk assessment is " *focused on the valuation of the potential consequences but very often these are limited to the expected damages in terms of direct and tangible expected costs*" (Giupponi et *al.*, 2013).

IPCC with the publication of SREX (2012), introduces the concepts of "risk", as presented in Figure 3.2, even if the "*causal chain of relations between climatic events and the concepts of vulnerability and exposure is not clearly defined*" (Giupponi et *al*., 2013).

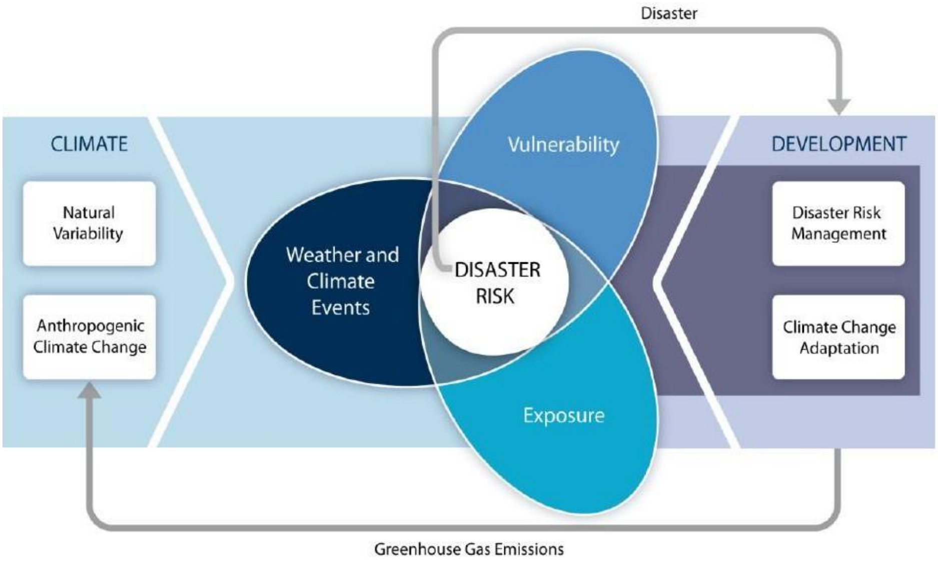

Figure 3.2 Managing the risk of extreme events and disasters to advance climate change adaptation (IPCC, 2012).

This difference is reflected in the way vulnerability is situated within the vulnerability assessment process. In the Climate change adaptation (CCA) stream vulnerability is considered as an output when in the Disaster Risk Reduction (DRR) stream, vulnerability is mainly regarded as an input to quantify the risk (Giupponi et *al.*, 2013). In both cases, vulnerability becomes an element of the "risk" process and to understand the overall picture we discuss of "risk assessment" that integrates the "vulnerability assessment".

Another aspect that emerges from the analysis of literature is that there is "*no practical solution for integrating and synthesizing the main references without facing the need to decide among contrasting definitions*" (Giupponi et *al*., 2013). Furthermore the definitions of vulnerability proposed in the scientific literature do not provide "*casual or functional relationships which are instead the basis for any attempt to develop operational algorithms for risk assessment*" (Giupponi et *al.*, 2013).

3.2.2 The Fifth Assessment Report: Towards a common theoretical framework?

IPCC has done a great effort in trying to unify terminology for vulnerability and risk since the publication of SREX (IPCC, 2012). In the recently published SPM of WG II (IPCC, 2014a), IPCC states "*Risk of climate-related impacts results from the interaction of climate-related hazards with vulnerability and exposure of human and natural systems*" (IPCC, 2014a). In the same report, IPCC introduces the role of non-climate drivers (anthropogenic climate change).

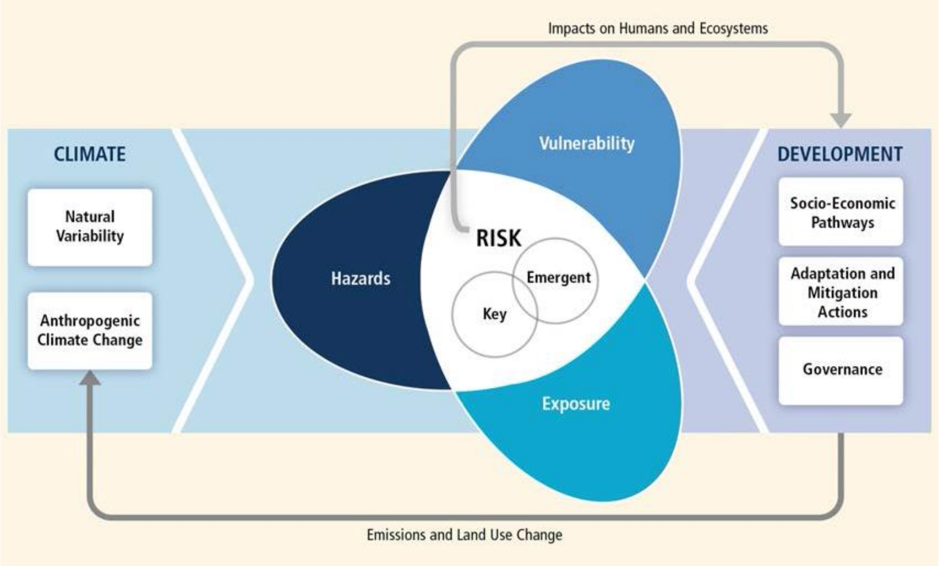

Figure 3.3 Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. (Source: IPCC, 2014b)

According to IPCC (2014b) 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. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur*".

Figure 3.3, proposed in chapter 19 of WGII of AR5 (IPCC, 2014b), shows Risk as a product of an interaction between hazards associated with climate change and variability on one side, and the vulnerability and its exposure to hazards on the other side (IPCC, 2014b). According to the WGII of IPCC (IPCC, 2014b), vulnerability and exposure are the result of development (socio-economic pathways, adaptation and mitigation actions and governance). Climate (left side) and development (right side) changes represent the key drivers of the different core components (vulnerability, exposure, and hazards) that contribute to risk (IPCC, 2014b). In synthesis Risk can be considered as a function of vulnerability, exposure and hazard.

Risk = f (hazard, vulnerability, exposure) (3.1)

To operationalize the risk function we need to disentangle the IPCC definitions for Hazard, Exposure and Vulnerability taking into account that for IPCC (2014b) vulnerability can be described as a function of Susceptibility and Resilience (IPCC, 2014b). The operation definitions for all the components contributing to risk are described in Table 3.2. The IPCC's definition for Susceptibility and Resilience (intended as capacity to cope and adapt) are integrated to operationalize Vulnerability.

Component	Definition	Source
Hazard	The potential occurrence of a natural or human-induced physical event or trend, or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.	IPCC, 2014b
Exposure	The presence of people, livelihoods, species or ecosystems, environmental services and resources,infrastructure, or economic, social, or cultural assets in places that could be adversely affected.	IPCC, 2014b
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.	IPCC, 2014b
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.	IPCC, 2012
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").	IPCC, 2014b

Table 3.2 IPCC's definitions of Risk components. (Source: own elaboration)

In Figure 3.3 IPCC introduces the concept of "key" and "emergent" risks. Risks are considered "key" "*due to high hazard or high vulnerability of societies and systems exposed, or both*" (IPCC, 2014b) while risk is considered "emergent" when "*arises from the interaction of phenomena in a complex system, for example the risk caused when geographic shifts in human population in response to climate change lead to increased vulnerability and exposure of populations in the receiving region*" (IPCC, 2014b).

These operational definitions of Risk, Vulnerability and Exposure allow building a methodological framework of reference through which to develop a conceptual definition of coastal risk and coastal risk assessment, as we will see in the next paragraphs.

3.3 The coastal risk concept according to IPCC AR5

We have analysed the concept of risk according to IPCC (2014b) and defined it as a function of vulnerability, exposure and hazard. Now we need to mainstream these considerations in the coastal context. To do this, again we are inspired by the contribution of WGII to AR5 and in particular Chapter 5 (IPCC, 2014b) referring to “Coastal Systems and Low-Lying Areas”. In Chapter 5, Risk on coastal systems is the outcome of climate and human development related drivers and exposure and vulnerability (Figure 3.4). Strangely, hazard is not specifically highlighted in Figure 6.1. We can presume that hazards are “embedded” in climate drivers.

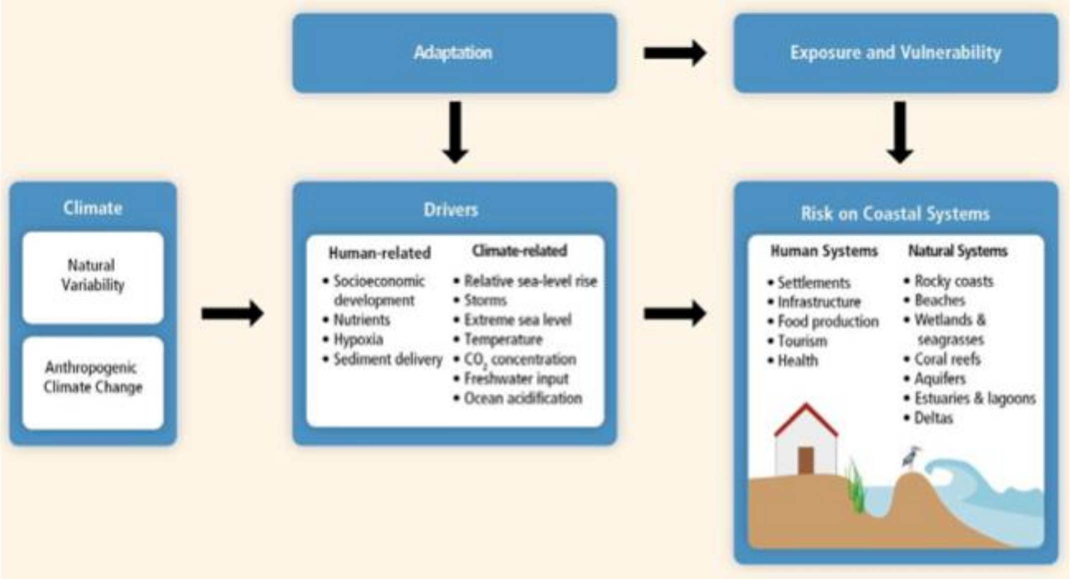

Figure 3.4 Risk on coastal systems. (Source: IPCC, 2014b)

The Coastal System is represented by the human system (settlements, infrastructure, etc.) and the natural system (beaches, wetlands, etc.). With the purpose to disentangle Risk on the coastal system, we need to describe forcing, exposure and vulnerability. For the aim of this research, we split drivers in two components: forcing and hazard. Forcing intended as the “external” driver and hazard as the “internal” driver of the coastal system. In this sense, we discuss of external drivers (climate and non-climate forcing) acting on internal drivers (existing hazards) that impact the coastal system.

It is very likely that climate and non-climate forcing will amplify the impacts generated by existing hazards. If hazards do not exist, forcing could create coastal hazards “ex novo”. Three main coastal hazards are considered which represent the most common coastal hazards in the Mediterranean: erosion, flooding and saltwater intrusion (ETC-CCA, 2011). Because potential damages associated with multiple hazards are different, we have decided to analyse the risk associated with forcing (climate and non-climate) to existing hazards by separately calculating each induced potential response. As presented in Chapter 2, the primary forcing for Mediterranean coastal zones are the socio-economic development (non-climate forcing) and the Sea Level Rise and Storms variability in frequency and intensity (climate forcing). Adaptation options can be implemented either trying to mitigate the drivers or modifying exposure and vulnerability or both.

The specificity of the proposed model is to consider existing hazards as they can be measured at current time before the potential effects of forcing. Evidently, it is not always possible to tell if the hazard, measured today, is caused by previous forcing. Furthermore, is even more difficult to understand if the current hazards were generated by previous human-related (e.g. urbanization) or climate (e.g. acceleration of SLR) forcing. For the purposes of this research, this aspect is irrelevant. What is important is to understand how climate variability added to other human-related changes could exacerbate existing hazard. For this reason the proposed model intends to describe the existing hazard, defined as the current measurable hazards on the coastal area under analysis. Once we have identified those hazards exist, it is necessary to predict how the forcing can multiply the effects of the hazards and how these hazards impact the coastal system. This requires an examination of the scientific literature on the effects of the main drivers of the impacts of natural hazards. For example, a beach, in natural equilibrium conditions, can be exposed to a natural phenomenon of erosion or accretion. In the case of climate forcing, interacting with human-induced forcing (e.g. artificial frontage) we could have an increase of coastal erosion (Nicholls et *al*., 2011; Ferreira, 2005). In the case instead the beach is in an accretion phase, the combined effects of climate and non-climate forcing may interrupt the accretion but not necessarily bring the beach profile in an erosion state.

Risk as indicated in Figure 3.5 is the result of the interaction of the coastal forcing factor (climate and non-climate) multiplied by the present coastal hazard (if coastal hazard doesn’t exist it can be created ex novo by forcing) with the coastal system. But what are the elements that characterize the coastal system in terms of its predisposition to being affected by natural hazards?

Beyond certain intrinsic characteristics of the system at risk, we need to understand the extent to which the system is exposed to the risk. The measurement of elements at risk in the system is given by the exposure that: “refers to the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected” (IPCC, 2014a). Under these conditions, we can say that the “coastal system” at risk can be defined by its vulnerability and exposure. The hazard component alters the coastal system, creating the risk as a function of vulnerability and exposure of the same system. Climate and non-climate forcing act directly on coastal hazards both by increasing the intensity, if already existing, either by creating them from scratch if not present in the coastal area taken into consideration. We can conclude that Risk on the coastal system can be defined as a function of vulnerability, exposure, hazard and forcing and integrate this part in the function 3.1 as following:

Risk = f (Forcing, Hazard, Vulnerability, Exposure) (3.2)

Figure 3.5 shows the components of the function of Risk on coastal system.

Figure 3.5 Conceptualization of the coastal risk for the research.

Once highlighted the relationship between forcing and existing hazards, it remains to describe the coastal system, considered as a complex system that is altered by the effects caused by hazards. It's easy to see that various coastal hazards interact with the system in different ways both in physical and socio–economic terms. If we consider, for example, physical-environmental impacts of Saltwater Intrusion, they act directly on coastal aquifers causing the reduction in freshwater availability. The effects of salinization of freshwater affect in a direct manner several economic activities such as agriculture, tourism and coastal urban settlements. In this sense, the first step is to structure the conceptual framework of the coastal risk model. The second-step, concerns defining the components of the “coastal system” in order to disentangle their behaviour as a function of different hazard impacts.

After having defined the general framework of coastal risk for this research, is now possible to proceed to the construction of the coastal risk function providing an explanation to the following research questions: How to operationalize the vulnerability and exposure factors to describe the coastal system through its physical, environmental, socio-economical components in an integrated coastal zone management approach?

How the different components interact under hazard pressures and how the impacts can be assessed through an integrated manner?

These questions are answered in the following paragraph.

3.4 The coastal system as a socio-ecological system

Coastal systems are dynamic and complex systems, whose geomorphological and ecological features are influenced by a range of interacting variables. They represent the interface between sea and continental processes that make coastal zones highly vulnerable to natural and human-induced changes. The complexity is given by the combination of coastal and marine ecosystems with highly populated areas, interacting in different manners. It is thus imperative to understand these processes regarding the coastal interface through a “systems approach” as defined by Hopkins et al. (2011). To operationalize the “coastal system” in the Risk assessment process we adopt the approach of ‘socio-ecological system’, or SES, to imply that there are aspects of coastal systems that require the integration of economical, social, and ecological aspects (Redman et *al*., 2004; Hopkins et *al*., 2011). In scientific literature, risk assessment is usually focused on physical aspects and less on social and economic issues (Giupponi et *al*., 2013). The integration of all the aspects is crucial for a comprehensive assessment of risks from coastal hazards. In this sense, one of the main weaknesses of risk assessment methods is the lack of integration of the concept of coupled social-ecological systems in their analysis.

The coastal system at risk can be identified by three interdependent sub-systems as follow (Van Beek, 2006; Hopkins et *al.*, 2011; Balica, 2012):

- The **physical-ecological** subsystem (PEs), in which the physical, and ecological processes take place;
- The **social and economical** subsystem (SEs), which includes the human activities related to the use of the PEs;
- The **institutional** subsystem (Is) that includes governance, administration, legislation and regulation, where the decision, planning and management process take place.

For the aim of this research, we need to describe the “coastal system” through the components defined for the risk function (3.2). At the same time operationalize these components into concrete and measurable variables. In this sense, the goal is to make operational definitions of vulnerability and exposure. This is done by describing vulnerability and exposure through the components of the three interdependent sub-systems at risk.

The approach proposed in this research aims to show how each element of the system, as well as the individual interactions, are vulnerable. Furthermore, this approach intends to demonstrate how and how much each the elements of the system are "exposed" (Balica, 2010). In this way are taken into account all the possible components and interactions that characterize the "coastal system." Coastal hazards stress the components of the coastal system, each of them belonging to one of the 3 subsystems (Physical-Ecological, Socio-Economical, Political-Administrative), and interactions affect the potential short-term and long-term damages (Balica, 2010). The components of each subsystem are assessed through specific variables, to understand the vulnerability and the exposure of the coastal system to hazards. We use Physical-Ecological and Socio-economical variables to describe vulnerability (result of the interaction between susceptibility and resilience) and exposure. The Political-Administrative component and related variables are considered only to illustrate Resilience. We assume that institutions (e.g. local authorities) play a primary role in sustaining and strengthening the adaptive capacity of the coastal system. The variables are resumed in Figure 3.6.

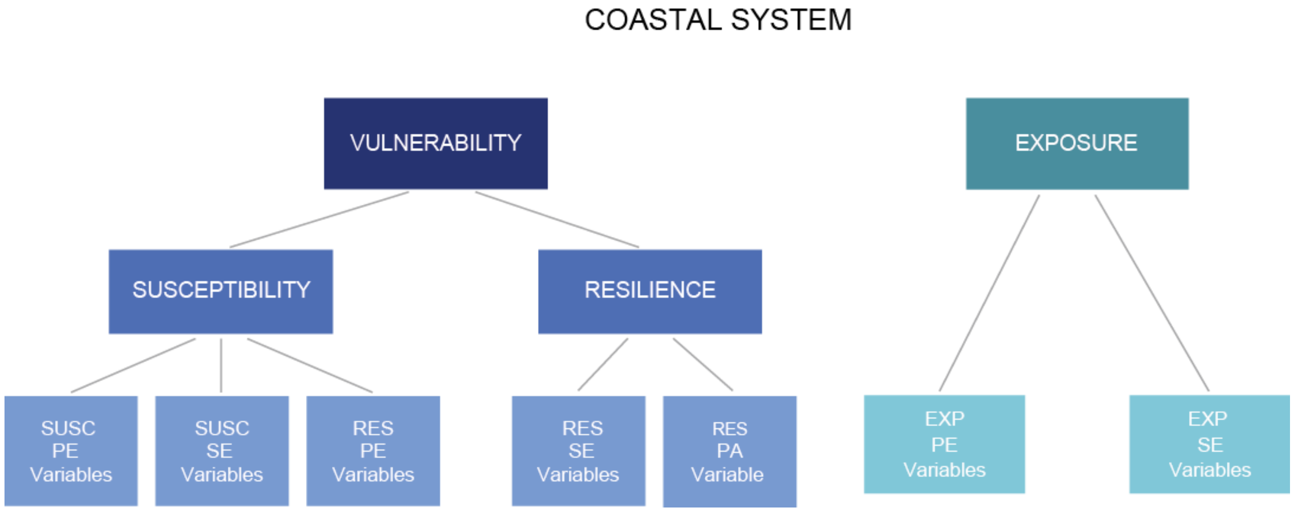

Figure 3.6 The coastal system described by Physical-Environmental (PE), Socio-Economical (SE) and Political-Administrative (PA) variables.

In this way, each component of the coastal system (PE, SE, PA) is described by mean of the variables related to each factor that compose the Risk function (Susceptibility, Exposure and Resilience). The main causes of risks, other than hazards, are vulnerability and the elements at risk, exposure, of coastal zones. The availability of data determines the accuracy of the quantification of risk (Lummen & Yamada, 2014).

Integrated risk assessment of the coastal area to a particular hazard requires a precise identification of the elements at risk (exposure), existing and potential vulnerabilities, and the hazard or the hazards to be assessed. The risk assessment highlights the predisposition of exposed and vulnerable elements to experience damages produced by the coastal hazards.

The first phase of risk assessment involves the identification of the geographical extent of various coastal hazards, their intensity and probability of occurrence (ONHW, 2005). The calculation of the levels of risk can be determined in relation to the different components that characterize the coastal system to assess: physical ecological, socio-economical and political-administrative. The various factors of the coastal risk process (forcing, hazards vulnerability, exposure,) can be defined through the components of the coastal system and assessed through numerical values. It is imperative to identify all the factors that contribute to risk and the interaction between factors and coastal system components. Therefore, we need to collect all available data necessary for defining such vulnerability and exposure considering that risk, vulnerability and exposure are not homogeneous.

Each component of Risk has varying influences and impacts on natural hazards (Lummen & Yamada, 2014).

3.5 Summary

Risk literature is fragmented in different disciplinary streams that can be grouped in two main categories Disaster Risk Reduction and Climate Change Adaptation (Giupponi et al., 2013). In the IPCC’s AR5, Risk is defined as the results of the interaction of hazards with vulnerability and exposure of human and natural systems" (IPCC, 2014a). In the same report, IPCC introduces the role of non-climate drivers (anthropogenic climate change). The Risk function proposed for the research integrates the forcing factor to highlight the interaction between forcing and existing natural hazards as the actual driver of risk. The resulting function is Risk = f (forcing, hazard, vulnerability, exposure). To operationalize the Risk function, we represent the “coastal system” as resultant of vulnerability and exposure factors. Adopting the SES approach we express vulnerability and exposure through Physical-Environmental (PE), Socio-Economical (SE) and Political-Administrative (PA) variables.

CHAPTER 4. ICZM AND CLIMATE CHANGE

4.1 Introduction

The principal objective of this study concerns the need to establish a framework for risk assessment based on an integrated approach. An integrated method takes into account all the multiple factors interacting to generate coastal hazards to which coastal areas are exposed.

The ICZM approach is the first necessary response to this need, and it is a further objective of this research to try to harmonize risk assessment with the ICZM approach developed in the framework of the Barcelona Convention.

While on one side, is it essential that research work remain in understanding how changes impact the Mediterranean coastal regions, on the other side, is equally important to ensure that research findings are accessible to coastal decision makers. Moreover is essential that adaptation policies are integrated with other policy planning and management of coastal resources within the ICZM framework. This approach is also supported by WGII of AR4 (IPCC, 2007), which highlights that “reactive and standalone efforts to reduce climate-related risks to coastal systems are less effective than responses which are part of integrated coastal zone management (ICZM), including long-term national and community planning” (IPCC, 2007).

The question of how climate change affects the Mediterranean coastal areas is a primary concern in the international debate within the framework of Barcelona Convention. Since the establishment of the Mediterranean Action Plan in 1975, and in particularly after the creation of the Priority Actions Programme in 1977, the ICZM approach has gained a central role in the Mediterranean coastal regions policies for coastal areas (Haines-Young & Potschin, 2011). This position has been strengthened by the entry into force of the ICZM Protocol in 2011. Addressing climate change related risks, is one of the main objectives of the ICZM Protocol as mentioned in Article 5, letter (e): “the objectives of integrated coastal zone management are to: prevent and/or reduce the effects of natural hazards and in particular of climate change, which can be induced by natural or human activities”.

Proof of how adaptation policies are increasingly framed in the context of the ICZM Protocol is evidenced by projects such as “Integration of climatic variability and change into national strategies to implement the ICZM Protocol in the Mediterranean” financed by the Global Environmental Facility (GEF) of the World Bank. The main objective of this project, started in February 2012, is to ”support to the implementation of the Barcelona Convention ICZM Protocol through the development of region-wide coordination mechanisms and tools to address climate variability in the Mediterranean Region“.

Despite the widespread use of ICZM in coastal planning and management in the Mediterranean, it has not been yet formalized a methodological approach for assessing the vulnerability of coastal areas explicitly based on ICZM. The opportunity to integrate a risk assessment method in the ICZM Mediterranean context raises several operational aspects that could allow the overcoming of some limitations of the existing methodologies:

- The integration into the analysis of some aspects often missing (e.g. non-climate drivers, socio-economic and cultural indicators);
- The integration of the risk assessment phase into the wider process of adaptation planning in coastal areas;
- The institutionalization of ICZM in coastal zone management policies and regulation at the regional, national and local level as a booster to spread of the instruments of risk assessment and adaptation measures in the Mediterranean.

This chapter intends to provide the ICZM conceptual and institutional framework behind the construction of a risk assessment method to be applied in the Mediterranean coastal regions. To this purpose the research work will be developed according the following research objectives:

- To highlight the need of an integrated approach in risk assessment;
- To explore the potential of ICZM as institutional and methodological framework in the Mediterranean for coastal adaptation to climate and non-climate driven changes;
- To analyse the provision of ICZM Protocol regarding the definition of the coastal setback zone to prevent natural risks resulting from coastal hazards.

4.2 The Integrated Coastal Zone Management

The coastal zone is an area of activity and interchange within and between physical, biological, social, cultural and economic processes. The interdependence of activities and resources in the coastal zone explains why a sectorial approach to coastal zone management has not been able to achieve satisfactory results. Every economic sector generates a range of impacts on various coastal resources, but their combined impacts generate acute problems for the resource base on which their survival depends on, and cause conflicts between sectorial interests[9]. Effective coastal zone management should be based not only on individual activities and their impacts, but also on the combined effects of sectoral activities on each other and coastal resources. Managing coastal

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[9] PAP/RAC - http://www.pap-thecoastcentre.org/about.php?blob_id=21&lang=en (accessed June 14, 2014)

areas requires an integrated approach capable of bringing together the multiple, interwoven, overlapping interests of these zones in a coordinated and rational manner, harnessing coastal resources for optimum social and economic benefit for present and future generations without prejudicing the resource base itself, and maintaining the ecological processes[10]. Competition over the allocation and use of coastal and marine resources, including space, is under constant increase. There is, therefore, a need to bring sectorial activities together to make a commonly acceptable coastal management framework. The term “coastal management” came into common use with the implementation of the United States Coastal Zone Management Act of 1972 introducing the recognition that a new coastal management approach was needed and “*since then, it has been widely recognised that a simple juxtaposition of sectoral approaches to management and land use planning is not appropriate to guarantee the sustainable use of natural coastal resources*” (Santoro, 2007).

Cicin-Sain and Belfiore (2005), provide a more detailed account of the evolution of the ICZM concept. Coastal areas require specific management approaches involving a system of relationships among actors who operate directly or indirectly in the coastal zones. Coastal resource management, coastal zone management, and integrated coastal zone management are used interchangeably to refer to the active management of coastal resources (e.g., animals, plants, and water) in such a way that these resources benefit the populations that depend upon them for hazard protection and environmental, aesthetic, and economic benefits (Santoro, 2007). Coastal resource management refers to a formal or informal set of rules, practices, technologies, economies, and interactions among humans and the natural resources (located both landward and seaward of the coast) that define how these resources are utilized and protected.

ICZM attempts to satisfy “*the needs of coastal communities through holistic, long-term socio-economic and natural resource development*”[11]. Furthermore, the application of ICZM can play a proactive role in climate change adaptation of coastal areas. More than one-quarter of the world’s population resides within a 100-kilometer distance and a 100-meter elevation of the coastline, with increases likely over the coming decades (Small & Nicholls, 2003). The human-induced pressures of this coastal population exacerbate the impacts of climate change on coasts (IPCC, 2007). Small islands are among those most vulnerable to climate change. Populated deltas, low-lying coastal urban areas, and atolls are key societal hotspots of coastal vulnerability, occurring where the stresses on natural systems coincide with high exposure and sometimes, limited access to adaptation resources (IPCC, 2007). Without adaptation, sea-level rise scenarios on the “high” end,

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[10] PAP/RAC - http://www.pap-thecoastcentre.org/about.php?blob_id=21&lang=en (accessed June 14, 2014)

[11] CANARI - http://www.canari.org/Benefitpeople.pdf (accessed June 15, 2014)

combined with other climate changes (e.g., increased storm intensity), are likely to render some islands and low-lying areas nonviable by 2100 (IPCC, 2007). Thus, effective adaptation is urgently required. Reactive and stand-alone efforts to reduce climate-related risks to coastal systems are less efficient than responses that are part of ICZM, including long-term national and community planning. ICZM can be used to address many climate-related issues and challenges. Nicholls et al. (2007) refer that when efforts to reduce climate-related risks to coastal systems are responsive and standalone they are less effective than when they are part of ICZM[12].

4.3 The formalization of the integrated coastal zone management concept in the Mediterranean: the ICZM Protocol

The Protocol on ICZM, entered in to force in 2011, aims at establishing a common framework for ICZM in the Mediterranean Sea, constitutes the first supra-State legal instrument specifically aimed at coastal zone management of the contracting parties of the Barcelona Convention (the 21 Mediterranean countries and the European Community) (Rochette & Billé, 2010). Previously, coastal areas were considered in a fragmented manner by international law: “sometimes a coastal zone was covered by protective measures set out in a text with a broader material or geographical scope; sometimes an activity, a habitat or a species specific to this area was covered by sectorial regulations” (Rochette et *al.*, 2012). Furthermore, the rare instruments aimed at moving beyond sectorial policies and guiding the national systems towards integrated coastal management remained confined to the realm of soft law. As reported by Rochette & Billé (2010) the ICZM Protocol is an innovative instrument at least for two important aspects:

1. It marks an important shift away from the regulation of coastal zones by international law, moving beyond the simple framework of recommendations in favour of binding legal obligations.
2. It has altered the traditional field of inter-State cooperation, moving into disciplines (administrative law, urban planning law, laws covering coastal economic activities, etc.) that were previously governed only by national laws.

A legal text like the ICZM Protocol is first of all the result of a negotiation process that has progressively led to the drafting of each of its provisions. It is therefore the result of a compromise that has gradually reconciled differing positions, bringing States together around a shared understanding. Furthermore, legal texts are not always easy to decipher: made up of numerous

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[12] GNRAC - http://www.gnrac.unifi.it/G3/Presentazioni2012/Satta-G3-GNRAC-2012.pdf (accessed July 5, 2’14

articles, often referring to other instruments and full of considerable editorial nuances, a careful reading and detailed analysis is required in order to fully understand their subtleties (Rochette, 2007). The Mediterranean ICZM Protocol is no exception to this rule.

Regional Mediterranean law is in fact one component of international environmental law and, as such, largely corresponds to its general characteristics. This is especially true of the nature of the text (Rochette, 2007). Thus, international environmental law and regional Mediterranean law are made up of "*joint conventions that contain both firm commitments, in the traditional sense of legal obligations, and soft law, made up of a set of intentions that the contracting States undertake to translate into binding standards*" (Kamto, 1998). Certain provisions of regional Mediterranean law therefore fall within the broader framework of international environmental law, "*a possibilist rather than prescriptive law, with very limited normative scope*" (Chabason, 1999). A protocol, which is binding by definition, may nevertheless contain provisions that seem more like suggested guidelines for contracting parties than imposed constraints (Rochette & Billè, 2010).

An in-depth analysis of the provisions of the ICZM Protocol therefore seems necessary in order to determine their true legal scope. The future implementation of the ICZM Protocol raises some fundamental questions, both theoretical and operational, about its application. Although, in accordance with the *Pacta sunt servanda* principle, no established rule prevents States from binding themselves in any matter, many fields generally escape the authority of international law. This is particularly true of urban planning, regional planning, institutional coordination and the participation of local actors (although the Aarhus Convention, already ratified by 9 Parties to the Barcelona Convention, has opened the way on this point). The ICZM Protocol, which concerns these different fields, is therefore an important innovation in terms of bringing international law into the traditional sphere of national laws.

4.4 ICZM Protocol and Climate Change

As emerged by Romieu et *al.* (2010) both the DRR than the CCA approach to vulnerability highlight the need to adopt an integrated approach in the construction of a broader risk assessments methodology. Furthermore, climate and non-climate induced environmental changes as well as socio-economic developments and their interaction must be considered (ETC-CCA, 2011). The ICZM Protocol has explicitly introduced the need for an integrated and strategic approach in order to ensure the sustainability of coastal areas and to address the broader exigencies of the climate change agenda (Ballinger & Rhisiart, 2011).

The ICZM Protocol includes a specific reference to the need of including policies and programmes for the prevention of natural hazards in ICZM: "*Within the framework of national strategies for integrated coastal zone management, the Parties shall develop policies for the prevention of natural hazards*" (Rochette & Billé, 2010). In article 6 and 23 of the Protocol there are two clear statements to the need of conducting preliminary assessment to risks (e.g. coastal erosion) generated by human activities, and climate change, in coastal management and then indirectly to the need of applying coastal vulnerability assessment tools to this aim (Rochette & Bille, 2010).

Preliminary Assessment (6i, 23-2)

"*Preliminary assessments shall be made of the risks associated with the various human activities and infrastructure so as to prevent and reduce their negative impact on coastal zones*" (6i).

"*The Parties, when considering new activities and works located in the coastal zone including marine structures and coastal defence works, shall take particular account of their negative effects on coastal erosion and the direct and indirect costs that may result*" (23-2).

Another relevant provision of the ICZM Protocol, stated in Articles 22, 23 and 24, refers to the need to conduct vulnerability and hazard assessments aimed at defining and implementing mitigation and adaptation measures. The Protocol refers to the need of enhancing international cooperation for responding to natural disasters.

Adaptation of coastal zones (22, 23-1, 24-1)

"*The Parties (…) shall undertake vulnerability and hazard assessments of coastal zones and take prevention, mitigation and adaptation measures to address the effects of natural disasters, in particular of climate change*" (22).

"*In conformity with the objectives and principles set out in Articles 5 and 6 of this Protocol, the Parties, with a view to preventing and mitigating the negative impact of coastal erosion more effectively, undertake to adopt the necessary measures to maintain or restore the natural capacity of the coast to adapt to changes, including those caused by the rise in sea levels*" (23-1).

"*The Parties undertake to promote international cooperation to respond to natural disasters, and to take all necessary measures to address in a timely manner their effects*" (24 - 1).

Coastal local communities, as well as national governments, are called to enhancing their capacity to respond to climate change impacts to socioeconomic and natural resources through adaptation planning. To achieve this objective, risk assessments must be integrated in the adaptation planning process and the formulation of adaptation strategies. Assessing coastal risk represents the first and essential step in the adaptation planning process. The aim is to establish the basis for defining valid adaptation measures. Assessing coastal zones vulnerability and exposure should allow a clear recognition of risks related, for example, to sea level rise or storm surges and the need for adaptation within relevant policies and programmes. The strongest statement that emerges in the ICZM Protocol is the Article 8.2 relating to the establishment of a 100 m setback zone, where new constructions are interdicted, as a measure of prevention against natural hazards directly and indirectly affected by climate change.

Establishment of the 100 Setback zone (8-2)

"*The Parties shall establish in coastal zones, as from the highest winter waterline, a zone where construction is not allowed. Taking into account, inter alia, the areas directly and negatively affected by climate change and natural risks, this zone may not be less than 100 metres in width, subject to the provisions of subparagraph (b) below. Stricter national measures determining this width shall continue to apply*". (8-2 a)

"*The Parties may adapt, in a manner consistent with the objectives and principles of this Protocol, the provisions mentioned above:*

1) For projects of public interest;

2) In areas having particular geographical or other local constraints, especially related to population density or social needs, where individual housing, urbanization or development are provided for by national legal instruments". (8-2 b)

"*The Parties shall notify to the Organisation their national legal instruments providing for the above adaptations*". (8-2 c)

The principle of a setback zone, proposed by the authors who drafted the Protocol[13], "*lies not only in the concern to protect an area of ecological and landscape interest which is very fragile due to the land-sea interface, but also the necessity to prevent natural risks resulting from the rise in sea levels related to climate change*".

The establishment of a setback zone of 100 m becomes a major tool to achieve the goal of preventing natural risks and adapting to climate change "*by protecting populations against the risks of submersion and erosion and, as we have seen, by reducing pressure on biodiversity and ecosystem services that are already under considerable threat*" (Rochette et *al.*, 2010).

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[13] UNEP/MAP, Draft Protocol on the integrated management of Mediterranean coastal zones, Meeting of MAP Focal Points, Athens (Greece), 21-24 September 2005, UNEP(DEC)/MED WG.270/5.

In several Mediterranean countries, law already establishes the setback zone. The most common approach to define the "setback zone" is the so-called "quantitative" option based on the "*establishment of a setback with a uniformly determined width for the whole of the national coastline*" (Rochette *et al.*, 2010). As reported in the Table 4.1, the 9 countries analysed have defined the setback zone according to a "quantitative" approach.

An exception if the case of the Sardinia Island that applying a "qualitative" approach adapts building regulations to the specific characteristics of coastal zones.

	Existing coastal policies on setback zones
Algeria	Law of 1 December 1990 on urban and regional planning imposed a building ban on "a strip of 100 metres in width from the shoreline". Article 18 of the Law of 5 February 2002 on coastal protection and development states that "this ban may be extended to 300 metres for reasons linked to the sensitive nature of the coastal environment".
Croatia	In, the 2007 Physical Planning Act establishes a "protected coastal area (PCA)", a zone "encompassing all islands, the continental belt 1 000 metres in width from the coastline and the sea belt 300 metres in width from the coastline". Articles 50 and 51 ban new construction works within a belt from 70 to 100 metres from the coastline under certain conditions.
France	The principle of protecting a continuous 100-metre strip was already set out in the National Planning Directive of 25 August 1979. Legislative confirmation by the Law of 3 January 1986 on coastal planning, protection and development, known as the Loi Littoral, clarified the principle, removing the numerous exceptions that existed under the previous regulation. Article L 146-4-III of the French Urban Planning Code thus provides that "outside urban areas, buildings and facilities are prohibited within a 100 metre coastal strip (…). A zoning and land use scheme may extend the coastal setback (…) to more than 100 metres when justified by the sensitivity of the environment or by coastal erosion".
Israel	The National Master plan for the Mediterranean Coast, adopted in 1983, aims to prevent development which is unrelated to the coast and to resolve conflicts of interest among land uses which require a coastal location. It includes a clause prohibiting development within 100 metres of the coastline, which may be extended, if necessary, according to the physical characteristics of the coast.
Morocco	In, the draft law on coastal protection and development establishes a setback zone of 100 metres, which may be extended when justified by the sensitivity of the environment or by coastal erosion.
Spain	In, chapter II of Coastal Law 22/1988 of 28 July establishes a protection zone of 100 metres, which may be extended to 200 metres upon agreement of the autonomous communities and the municipalities concerned. In this zone, the construction of establishments for residential use is prohibited. It should be noted that the application of this law was left in abeyance for a long time, leading the Spanish government to adopt in 2008 a strategy to recover land that has been illegally built upon in this zone.
Turkey	Coastal Law 3621/3830 provides for a 100 metre "shoreline buffer zone" in which facilities aimed at the protection of the shoreline or the use of the coast for the public interest may be built if authorized by a land use-planning permit. This category of buildings includes piers, ports, harbours, berthing structures, quays, breakwaters, bridges, seawalls, lighthouses, boat lifts, dry berths and storage facilities, salt production plants, fishery installations, treatment plants and pumping stations.

Egypt	The 1994 Environment Law submits the construction of any establishment within 200 metres of the coastlines to the permission of the competent administrative authority, in coordination with the Environmental Affairs Agency.
Italy	The Law n. 431/1985 called “Galasso” calls for special attention to be given to the 300-metre strip by prohibiting any new building. Unique in its kind is the case of the Sardinia, the second largest island of the Mediterranean with more than 2000 km of shoreline, the first region in Italy to adopt a landscape plan based on the European Landscape Convention and through the Regional Law 8/2004 "rules for urgent provisional safeguard and landscape planning of the regional coastal areas", were established extremely restrictive provisions for the coastal areas (identified with the band of two kilometres from the shore line), which would remain in force until the approval of the Regional Landscape Plan (PPR), the process of defining, adoption and approval of the same law defines “Salvacoste” in an extremely rigorous . The legislation defines twenty-seven Areas of landscape that make up the First Homogeneous Area, corresponding to the coastal territory where the preservation of coastal ecosystems and coastal landscape takes precedence over all other uses. They are in fact only allowed the recovery and redevelopment of the existing buildings. The definition of the coastal setback in Sardinia is based on a " qualitative" approach.

Table 4.1 Existing institutional framework of setback zones in the Mediterranean. (Source: adapted by Rochette et *al.*, 2010)

As emerge in the Table 4.1, excluding Croatia and Italy, the coastal setback, under protection by law, in the majority of Mediterranean countries is 100 m. In the case of France the setback line can be extended to more than 100-metre when justified by specific hazards like coastal erosion.

Concerning the other Mediterranean States that have not yet established a coastal setback zone, Rochette et al. (2010) reports that there is a “special attention” in terms of legal protection to the areas closest to coastlines.

From this analysis Rochette et al. (2010) has drawn the following conclusions: “(*i) the institution of the general principle of a ban on building in a coastal strip that varies in width from country to country, (ii) the use of geographical considerations to justify the extension of this zone, (iii) the definition of exceptions (or dispensations, etc.) that vary in scope and may or may not be well defined*”.

From this general analysis, it can be assumed that the definition of setback areas may represent a valid measure of adaptation to risks arising from natural hazard. This aspect is certainly even truer if the setback zone is defined by a “qualitative” approach. Through the qualitative approach, it is possible to define the coastal setback zones in terms of exposure and sensitivity, introducing scenarios of climate change, particularly SLR. In this direction, there emerges the need to make the instrument of vulnerability assessment to the functional description of the coastal setback zones.

The definition of a binding limit of 100-metre, especially in countries where there is no specific "Coastal Law", still represents an important step forward in terms of risk mitigation and adaptation planning. And it is precisely this dilemma that arises in the following research question: How to define the coastal setback zones according to climate change scenarios?

Before defining the coastal setback zone, we need to define the coastal exposed to present and future potential hazards. The setback zone represents a chosen level of protection for selected planning period. Healy (1993) describes this area as "*a line on the ground beyond which, on the balance of evidence, and in the light of scientific knowledge of the moment, it would be prudent to limit (not necessarily completely avoid) development*". Another definition of coastal setback is proposed by Ramsay (2012): "*planning tools to exclude or restrict beachfront development and land use within areas potential threatened by coastal hazards or to inform trigger points for the relocation of buildings*".

The two definitions are very similar and present very practical indications for coastal planners. In other words, the coastal setback zone can be considered as the upper limit of the hazard zones, and it should represent the maximum inland distance from the shoreline.

If we consider coastal erosion and coastal flooding as present and potential future hazards, the setback line coincides with the upper limit defined by the flooding hazard zone. In fact in a future scenario the flooding event will develop starting from the maximum erosion level.

The definition of coastal setback must take into account current knowledge on coastal hazards and projections of future change, with related uncertainties, depending on the characteristics of the physical-ecological system and the socio-economic system of the coastal area under study (Ramsay, 2012). Furthermore coastal setback represents a decision tool on "*the management of different hazard types, the level of accepted residual risk (and therefore uncertainty) and the timeframes for planning implementation*" (Ramsay, 2012).

These issues, therefore, need the definition of a hierarchy of values for decision. Some development choices may, in fact, increase the level of accepted residual risk for a given coastal area, and this would require a precise cost-benefit analysis. The choice of some principles behind the definition of the coastal setback is, therefore, long overdue.

A first answer in this direction is provided by the New Zealand Ministry for the Environment. MfE-NZ defined four general principles (see Table 4.2) aimed at planning of the coastal setback for coastal local authorities in New Zealand (MfE-NZ, 2008):

Precautionary approach	A precautionary approach is adopted when making planning decisions relating to new development, and to changes to existing development within coastal margins. Decision-making takes account of the level of risk, utilizes existing scientific knowledge and accounts for scientific uncertainties.
Progressive risk reduction	New development is not exposed to, and does not increase the levels of, coastal hazard risks over their intended serviceable lifetime. Progressively, the levels of risk to existing development are reduced over time.
Coastal margin importance	The dual role of natural coastal margins as the fundamental form of coastal defence and as an environmental, social and cultural resource is recognized in the decision-making processes and, consequently, natural coastal margins are secured and promoted.
Integrated, sustainable approach	An integrated and sustainable approach to the management of development and coastal hazard risk is adopted, which contributes to the cultural, social and economic well-being of people and communities.

Table 4.2 The 4 principles defined by the New Zealand Ministry for the Environment for the definition of the coastal setback zones. (Source: MfE-NZ, 2008)

The definition of coastal hazard zones and setback zones is one of the most critical phases of coastal planning and ICZM process for local decision makers. A practical method to define the limits of the coastal area affected to natural hazards such as inundation, coastal erosion and saltwater intrusion is proposed in chapter 6. In this context, the vulnerability and risk assessment process must focus on the coastal areas included in the hazard zones.

4.5 Summary

The ICZM approach represents a useful tool to build a risk assessment framework based on an integrated approach. ICZM allows taking into account all the multiple factors interacting to generate coastal hazards to which coastal areas are exposed. ICZM is used to address many climate-related issues and challenges and as reported by Nicholls et al. (2007) when efforts to reduce climate-related risks to coastal systems are part of ICZM process they are more efficient.

The ICZM Protocol is considered the most innovative legal instrument in the Mediterranean to mainstream the ICZM approach at all governance levels (e.g. regional, national and local).

The ICZM Protocol explicitly refers to the need of conducting a preliminary assessment to risks generated by human activities, and climate change (Rochette & Bille, 2010).

The ICZM Protocol proposes the definition of a setback zone as an area to “prevent natural risks resulting from the rise in sea levels related to climate change”.

Many efforts have been made by Mediterranean countries to define a setback zone.

The ICZM Protocol provisions regarding the definition of the setback zone claims to develop a methodological approach for the definition of coastal hazard zones.

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CHAPTER 5. REVIEW OF COASTAL VULNERABILITY AND RISK ASSESSMENT METHODS

5.1 Introduction

This chapter intends to review existing coastal vulnerability and risk assessment methods and to understand how the scientific research on vulnerability and risk assessment can be translated into practical operational tools for coastal risk assessment.

It should be stated from the very beginning that the comparative analysis carried out in this chapter, focuses on methods modelling features rather than on the theoretical concept of vulnerability and risk discussed in Chapter 3. The vulnerability and risk methods selected for this comparative study have been developed before the publication of IPCC'sAR5 therefore they could not take into account the new IPCC's conceptual framework for Risk on coastal systems. With that in mind, we proceed to the definition of the characteristics required for the assessment tool and the research questions.

The tools should be easily accessible to coastal planners and practitioners and easily integrated by local decision makers in the adaptation planning process. A precise definition of local scale for vulnerability assessment is the one proposed by McLeod (2010) and refers to geographic areas ranging from less than 1 km2 to 10 km2. In the same research McLeod et al. (2010,) answers to the first emerging research question: "*Which are the key objectives of coastal planners, practitioners and decision makers to implement a vulnerability assessment tool at the local scale?"*

The key objectives are resumed in the Table 5.1 reworked from McLeod et al. (2010).

Interested stakeholders	Key objectives
Local decision makers and planners	Identifying conflicts among local communities, economic activities and coastal habitats. Identify which adaptation strategy between retreat, accommodate, and protect (Bijlsma et *al.*, 1995; IPCC, 2007) must be adopted to safeguard ecosystems, people, infrastructures, etc. due to climate change impacts, Identify positive effects and possible impacts of adaptation measures.
Economic actors	Identify which adaptation strategy between retreat, accommodate, and protect must be adopted to safeguard economic activities exposed to risk
Conservation agencies	Assessing the vulnerability of coastal habitats (e.g., wetlands, beaches) and species (e.g., sea turtles, nesting birds) to sea-level rise impacts
Educational institutions, NGOs	Raising awareness of the impacts of sea-level rise on coastal habitats and communities

Table 5.1 Key objectives for coastal vulnerability assessment at the local scale. (Source: reworked from McLeod et al. 2010)

The other relevant research questions are:

- Which is the state of the art of vulnerability and risk assessment methods at the international level?
- Is there an existing vulnerability and risk assessment tool easily applicable to the wide and diverse variety of Mediterranean coastal regions?

These questions are answered by conducting a literature study on the different approaches and methods for assessing vulnerability and risk. The research approach is based on documentary analysis, web search and participation to various conferences and workshops.

5.2 Methods review

Coastal communities and ecosystems, especially in low-elevation regions, are exposed to coastal hazards impacts directly or indirectly resulting from climate and non-climate changes. The task of the local planners before proceeding with the definition of an adaptation plan is to analyse the coastal assets a risk to coastal hazards. Local socio-economic and ecological systems and their vulnerability and exposure have to be defined unambiguously for the implementation of effective adaptation planning. The first step in defining characteristics of the optimal vulnerability and risk assessment tool is to define the “research problem” by answering the following three questions (Tonmoy et *al.*, 2012):

- The vulnerability to which climate related stress or hazard is to be assessed (e.g. SLR and storm surges)?
- Which socio-ecological system (e.g., coastal ecosystem, local community, tourism sector, etc.) is the object of the study?
- Which component of the coastal system, intended as a socio-ecological system, is to be assessed?

In the case of this research, focus is on a coastal unit including urban settlement and ecosystems. The climate-related stresses are SLR and Storm surges. Coastal Hazards are saltwater intrusion, coastal flooding and erosion. The coastal assets represent the particular target of the local adaptation planning process, and they can be very different from one destination to another. As an example, the coastal assets could be the well-being of households living at or near the beach or the integrity of the public infrastructures at or near the beach or both of them. A coastal asset could also be the ecosystem conservation (Tonmoy et *al.*, 2012). The method applied for this research can be summarized as follows:

- Define the main “selecting criteria”, emerged by the previous observations, satisfying the conditions defined for this research;
- Evaluate the compliance of existing coastal vulnerability and risk assessment methods with these selecting criteria;
- Select the “most” suitable method to be applied at the local scale in the Mediterranean coastal regions.

5.2.1 Requirements

Existing methods to assess coastal vulnerability and risk differ in complexity, in the number of processes they include, in the application at various scales (McLeod et *al.*, 2010) and their outputs. Following the considerations on the characteristics of a coastal community in the Mediterranean, in terms of its vulnerability and exposure to climate and non-climate changes, it is possible to determine the requirements that coastal vulnerability and risk assessment methods must possess. These requirements are described in the Table 5.2.

Climate and non-climate drivers of change and related impacts in the Mediterranean sea		
1	Include SLR projections under different Climate Change scenarios and if available other climate drivers projections like storm surges	The method should include the possibility to analyse various scenarios based on different assumptions, including the time horizons (e.g. 2050 and 2100) (ETC-CCA, 2011).
2	Integrate non-climate drivers	Include non-climate drivers like urbanization and tourism development that characterize the Mediterranean context.
3	Incorporate physical, ecological and socio-economical assessment assets	The method should assess both socio-economic assets (e.g. population, tourism, agriculture, etc.), physical (e.g. infrastructures) and ecological (e.g. protected areas, wetlands, etc.)
4	Applicable to different typologies of coastal zone and coastal ecosystems	Applicable to different coastal profiles: sea cliffs, stony beaches, salt marshes, Sand dune beaches, etc., and applicable to different coastal ecosystems: Wetlands and estuaries, Marine habitats, Coastal forests and dunes.
Suitable with the conditions of a local coastal community		
5	Applicable at the local scale	To be suitable for its application at local scale the tool must reach the minimum level of 1 - 10 km2 in terms of coastal area
6	Not expensive	The costs for the purchase and the implementation of the method must be affordable for the budget of a local coastal community
7	Easy-to-use	The use of too must be intuitive and accessible for practitioners more than for scientists
Outputs useful for supporting local adaptation policies/measures		

8	Provide specialized analyses to assist local policy makers in the adaptation planning process.	A key element for selecting the best method is its capacity to be useful 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 respond
9	Outputs of Risk assessment tool easily to integrate with existing planning	Information effectively integrated into the planning process, such as maps, indices and indicators, or charts

Table 5.2 Requirements for the coastal vulnerability and risk Assessment methods.

In the scientific and technical literature, just few guidelines (e.g. Abuodha and Woodroffe, 2006) exist to support coastal managers and policy makers to identify an appropriate method for modelling sea-level rise impacts (McLeod et *al*., 2010). Moreover, existing guidelines ones are too broad to provide practical advice or to be applied to the Mediterranean context. Recent efforts have been made to assist coastal managers in the selection of an appropriate method for conducting a coastal vulnerability assessment (McLeod 2010, ETC-CCA 2011). Other minor publications have been prepared by NOAA (2010a), Burkett and Davidson (2012), NCCOE (2012) and Rozum and Carr (2013), all specially designed at the country level (e.g. USA, Australia).

We need to highlight that the majority of methods analysed by McLeod et *al*. (2010) and ETC-CCA (2011) refers to vulnerability concept as mainly incardinated in the theoretical framework of IPCC (2007). All these studies had been carried out before the definition of a new conceptual framework for coastal risk proposed by IPCC (2014a; 2014b).

The most recent and comprehensive work on coastal vulnerability assessment methods evaluation is the technical paper of ETC-CCA (2011). ETC-CCA explores which available methods (indicators, index, GIS and model-based methods) can be operatively and concretely applied for assessing coastal vulnerability to climate change (ETC-CCA, 2011). The spatial scale of application being the European and Regional Sea contexts.

In ETC-CCA's research, 14 different models were compared. The most relevant differences of this research compared to the ETC-CCA technical paper are indicated in Table 5.3.

	Scale of application	Geographical area of interest
Present research, 2014	Local	Mediterranean coastal regions
ETC-CCA, 2011	Regional	European regional seas

Table 5.3 Main differences between the present research and the ETC-CCA comparative analysis.

Based on the classification made by ETC-CCA, 4 categories of tools are defined amalgamating index and indicators based methods in the same category. The “visualization tools” have been added as a category because they are often applied as a simplified vulnerability assessment tool. This research identified 26 models/tools, divided set in 4 categories as presented in Table 5.4.

Category	Description	Methods
Index/Indicators based methods	Index methods are based on the quantitative or semi-quantitative evaluation and combination of several variables meanwhile indicator-based approaches, express the vulnerability of the coast by a set of indicators that characterise 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 more or less broad indicators precisely. 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 that aggregated indexes and indicators according to an appropriate set of weights.	CCFVI, CVI, Multi-Scale CVI, CVI (SRL), RCVI, SoVI, Composite Vulnerability Index
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).	SCAPE, SMP, BTELSS, DELFT 3D, DIVA, FUND, GVA, HAZUS-MH, InVEST, RACE, Regis, SimClim, SLAMM
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.	EVA, DESYCO, DYTTY- DSS
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 DSS. Visualization tools “are generally easy to use and do not require specialized software or hardware” (Rozum & Carr, 2013).	Sea Level Rise and Coastal Flooding Impacts Viewer, CanVis, COSMO.

Table 5.4 List of coastal vulnerability assessment methods selected for the research. (Source: own elaboration)

Another relevant aspect to integrate with the development of a coastal vulnerability and risk assessment tool is the need to consider the uncertainties and how this increase from global to regional-local scale. The preparation of a vulnerability assessment study, at the local level, presents several gaps in the information available. First of all, the downscale of climate forcing projections with related uncertainties. The current state of the art, confirmed by RACCM’s work (Navarra & Tubiana, 2013) doesn’t seem very much change from what stated by UNEP & EEA in

1999: “*data obtained on the Mediterranean spatial scale are still some what unreliable for the assessment and solution of practical problems*”. Recently, numbers of study have been carried out with the aim to determine the climate impacts and relative SLR, but future projections are difficult because of uncertainties (Gualdi et *al*., 2013). A brief description of the methods is presented in Table A.1 (Appendix A).

5.2.2 Comparative analysis

The principal aim of the research is to select an easy to use coastal vulnerability and risk assessment method to be applied at the local level in the Mediterranean. The tool must be easily implementable by the local policy makers through the support of local experts. Assessing vulnerability and risk requires contributions from a variety of disciplines, institutions, local decision-makers, resource users and residents (Dolan & Walker, 2004). The application of coastal risk assessment methods at the local level must consider local capacities to deal with change and the institutional frameworks that govern decisions at different scales. This condition requires that research must be grounded at the community-level and involve local knowledge systems as well as cultural interpretations of the environment (Dolan & Walker, 2004). In order to identify the most suitable method corresponding to the aims of this research, a comparative analysis is constructed in two phases. The first phase seeks to analyse each of the 26 methods compared to the nine requirements given in section 5.1. Are admitted to the second phase only methods that meet the nine requirements simultaneously. Methods that don’t respond positively to the first phase are no further analysed. In the second phase, the level of coherence of the selected methods to each requirement is additionally analysed by applying a qualitative approach. The methods are analysed in light of the “requirements” as presented in Table 5.2. The analysis presented in Table A.1 (Appendix A) represents an obvious simplification that cannot always grasp the articulation and complexity of the methods developed, but it is also necessary for an expeditious comparative analysis. Some of these methods as BTELSS, CVI, CVI-SLR, DESYCO, DITTY-DSS and DIVA, have already been used in the Mediterranean context.

The full and partial compliance of the 26 selected methods with the nine proposed requirements is summarized in Table A.2 (Appendix A), using a simple assessment based on three levels (☺ fully compliant, 😐 partially compliant, ☹ no compliant) that resumes the more exhaustive explanation of Table A.1 (Appendix A).

Only four methods are fully compliant with all the nine requirements defined for this research. The tools are: SimCLIM, Multi-Scale CVI, CVI – SLR and Desyco. CCFVI is almost fully compliant with

8 positives out of 9, and BTELSS, Composite Vulnerable Index, DITTY-DSS and Regis are compliant with 7 positives out of 9.

To select the best method suitable to the local context of a Mediterranean coastal area the next phase is an in depth analysis of the 4 pre-selected methods.

CVI - SLR

The CVI- SLR index includes the Climate Change scenarios and in particular SLR projections and relative physical impacts such as coastal erosion, inundation, flooding due to storm surge and sea water intrusion (Özyurt & Ergin 2009). Non-climate drivers related to human activities in the coastal areas such as land use and regulation are considered (Özyurt et al., 2011). The model incorporates a complete set of physical, ecological and socio-economic vulnerability targets (Özyurt, 2007). Social vulnerability is described by the entire group of indicators (e.g. health, education). Less attention is devoted to economic sector indicators and to cost benefits analysis. The Index is theoretically applicable to all coastal zones (ETC-CCA, 2001). Concretely the CVI - SLR has been applied just in the Goku Delta in Turkey. The Index can be applied to the local scale cause it doesn’t depend on a particular spatial resolution. Like other Indicator and Index methods, CVI-SLR is very simple and easy to use to implement at the local level (ETC-CCA, 2011). The costs are the men-hours for gathering available local data, defining each parameter, calculating the impact sub-indices and the overall vulnerability index (Özyurt, 2007). CVI-SLR like other index/indicators tools can be very useful for communicating SLR impacts to local stakeholders (ETC-CCA, 2011). Main limitation of this approach is the lack of a more robust quantitative assessment and the direct identification of adaptation measures (ETC-CCA, 2011).

DESYCO

DESYCO provides exposure scenarios based using the output of numerical models simulations on change simulation from global climate to the Mediterranean scale (Torresan et *al.*, 2010). In Torresan (2010) the subsidence map to calibrate sea level rise has been included. The model doesn’t consider socio-economic non-climate drivers. DESYCO includes analysis of different climate change impacts (e.g. storm surges) and affected ecological (e.g. water, soil, biodiversity) and socioeconomic (e.g. fishery, agriculture) resources (ETC-CCA, 2011). It can be applied to the different type of coastal zones. It has been applied from regional to sub-national scale, and the spatial resolution can be adapted to data availability even if the model is applicable only to the study area of concern (ETC-CCA, 2011).

The main gaps of DESYCO observed by ETC-CCA (2011) are “*data availability, diversity of data sources, formats, and spatial scales that introduced geographical errors; and for now, the limited availability of well differentiated test areas*”. More recent applications of DESYCO (Torresan et *al.*,

2012) have augmented the number of test areas. DESYCO it is integrated with GIS and it’s useful to assist coastal managers in adaptation planning.

Multi-scale CVI

The Multi- scale CVI, beside the characterization of physical elements, also integrates a broad set of socio- economic variables including cultural heritage and conservation designation (McLaughlin et al., 2002). The vulnerability assessment targets are represented by variables that are separated into three sub-indices: a coastal characteristics sub-index (resilience and susceptibility to erosion); a coastal forcing sub-index; and a socio-economic sub-index based on infrastructures potentially at risk (McLaughlin, 2010). The three sub-indices contribute to the calculation of the overall index expressed in the form of vulnerability maps (McLaughlin & Cooper, 2010).

The index can be employed at a local level and like the other models; the data used to produce the indicators varies according to the scale of application. It must be highlighted that the model does not clearly define how to transpose the sub-indices in a GIS environment. The model is not expensive and has an easy calculation process. The Multiscale – CVI doesn’t address adaptation measures (ETC-CCA, 2011).

SimCLIM

The model allows users to examine climate variability and extremes as well as long- term change. One of the main characteristics of SimCLIM is the “scenario generator” which uses a “pattern scaling” method (Warrick, 2009). It supports integrated impact analysis at various spatial scales. SimCLIM it is applicable to the different type of coastal zones (ETC-CCA, 2011). The geographical size, from global to local, and the spatial resolution is subject to “*computational demands and data availability*” (Warrick, 2009). SimClim is flexible in structural modification and study area (Warrick, 2009) and it has been applied worldwide from regional to local scale showing is adaptability to the Mediterranean context. Concerning the costs SimCLIM varies from low (100 US$) to-medium (400 US$) cost depending on user category. It is user-friendly and quick-running. SimCLIM is fully compatible with the most popular GIS software. The use of SimCLIM requires medium-high expertise and training (ETC/ACC, 2010b). Adaptation measures are addressed in the model (ETC-CCA, 2011).

5.3 Discussion

The Mediterranean area is characterised by a fast population growth, mainly concentrated along its coastline. Tourism development in addition to population growth generates significant environmental, social and economic impacts. These impacts are accelerated and exacerbated by climate-driven pressures like sea level rise and coastal floods.

The complexity and diversity of the Mediterranean coastal areas in terms of physical - environmental, socio-economic and political-institutional require a major effort to coordinate policies to mitigate and adapt to climate and non-climate drivers. Within the framework of the Barcelona Convention the ICZM Protocol refers to the need to assess the risks related to climate and non-climate drivers such as the intense human activity in coastal areas. Human-induced drivers are likely to increase the risks generated by the SLR and storm surges.

In the last decades, several vulnerability studies have been made of those Mediterranean coastal areas supposed to be already affected by climate changes effects. These studies have been mainly driven by academic purposes and in particular with the aim of implementing scientific models in real world (Ozyurt, 2007; Snoussi et *al*., 2008; Torresan, 2010; Khouakhi, 2013). What appears from the literature review developed in the present work, is that vulnerability and risk assessment methods have not been developed starting from the needs of the local communities. The vulnerability and risk assessment studies, developed so far, are primarily driven by top-down processes in which local managers and other local stakeholders are not involved. This aspect represents a concrete weakness common to several selected methods. The involvement of coastal managers since the preliminary phases of the method implementation facilitates the use of the tool as a Decision Support System (Lyalomhe et al., 2013). Another important limitation in developing these methods is that adaptive capacity and response of systems to climate change drivers and related impacts are often unknown (McLeod et *al*., 2010). The comparative analysis brought out sharply the need for disposing of, extremely easy to use methods to implement at the local level likewise the need to integrate assessment outputs in the adaptation planning process.

To date, according to the results of this research, do not emerge specific application of coastal vulnerability and risk assessment method within ICZM or coastal planning processes and more specifically in adaptation strategies. The case of the Nile Delta is emblematic in this regard. Many studies and research have been developed (EL Raey, 1999; Ismail et *al*., 2012) and same number of concrete actions of coastal zone management and adaptation planning, among which one the most significant is the UNDP project “Adaptation to Climate Change in the Nile Delta through Integrated Coastal Zone Management”. In most cases, research and adaptation planning have passed through two parallel pathways. The case of Ismail et al. (2012) differs from the others as his research on coastal vulnerability assessment, aimed to the design review of the seawall to protect the lowland area, below mean sea level of the Nile Delta (Ismail et al., 2012). Another good example of interaction between science and coastal planning and management is the UNEP project ‘‘Vulnerability and Adaptation Assessment to Climate Change of Morocco’s Coastal Zones’’ financed by GEF. The most relevant researches regarding coastal vulnerability assessment of the Moroccan coastal zones (Snoussi et *al*., 2008) were funded by the project and results integrated with the adaptation strategies.

The overview of 26 methods allows drafting some preliminary conclusions:

- Vulnerability and Risk assessments should include non-climate drivers (e.g. tourism pressure) and interactions between climate and non-climate drivers (methods should include socioeconomic indicators as well as the political-administrative framework);
- Importance of spatial scale in developing methods that must be compliant with the nature of the hazard to be assessed and related importance of data availability at various scales and related limitations of some methods demanding too much data to be run;
- It is essential that vulnerability and risk assessment methods represent a robust decision-making support instrument for ICZM and coastal planning. So it must produce information that is updated, based on scientific evidence, "synthetic" (e.g. risk maps and indicators), easily understood, and easily integrated into strategies and plans. Furthermore, a paramount input of the method to comply with the ICZM Protocol framework is the support to define the coastal hazard zones and the setback lines.

For further research, it was decided to select only the methods that are fully compliant with the required prerequisite.

The four analysed methods show a regional to local scale applicability. Just some of the methods considered show high flexibility and adaptability to different scales and different coastal zones. In the comparative analysis developed in this Chapter, it emerges that the Index-based tools (CVI-SLR and Multiscale – CVI) present several advantages like to be easily upgradeable. Indexes used for the assessment process can be added or eliminated, and the formulas easily updated. The formula employed for the calculation are readily understandable for coastal managers and practitioners. The data are complete, because there are physical data (e.g. geomorphology, sediment budget and water depth at downstream) and human influence (e.g. reduction of sediment supply and land use pattern) parameters. It integrates socio-economical, ecological and physical parameters. It can be applied to the coastal zone in general, and CVI- SLR accurately assesses impacts produced by SLR (ETC-CCA, 2011). Another specific added value of an Index-based method is that it presents any limit in terms of scale applicability.

Among the methods based on dynamic computer models, SimCLIM satisfies all the selecting criteria defined for this research. Its strengths are the “open-framework” features that allow its use in very different geographical and spatial conditions. SimCLIM is very flexible, and it can be customized to local conditions (climatic, physical and socio-economical). Another advantage is the support provided by the developer (ClimSystem Ltd) and the extended literature background on a real application worldwide. The unique limitation seems the fact that, till present, has not been applied in the Mediterranean coastal zone.

DESYCO was initially developed for the regional level but in principle it could also be applied at the local scale. DESYCO was tested in the coastal area of the North Adriatic Sea (Italy) and of the Gulf of Gabès (Tunisia) within the CMCC-FISR and CANTICO projects and into the Upper Plain of Veneto and Friuli-Venezia Giulia regions (Italy) and to the Esino river basin in the Marche region (Italy) within the SALT and TRUST projects. The current limitations of DESYCO as described in the CMCC website will be overcome with future development including the analysis of multiple hazards for the integrated assessment and management of different types of risks.

The latest considerations regard the choice between the Index based (CVI – SLR or Multiscale – CVI) or GIS/computer basis (SimCLIM and DESYCO) tools for the Mediterranean regional and local scale. If we consider the need to create an expeditious vulnerability and risk assessment method, without modifying the method features, the CVI tools are the most effective choice. This consideration is confirmed by the extensive diffusion of CVI applications worldwide. In terms of adaptability, it should be emphasized that SimCLIM has several additional modules but that at the same time, only its developers can operate the software upgrade. The upgrade and adaptation of the CVI tools to the local conditions does not require high scientific expertise that makes the CVI tools preferable in the context of weak financial resources and small capacities of coastal managers and practitioners.

The acceleration of the combined effects of climate and non-climate drivers requires an international effort to make available the necessary resources for the development and implementation of coastal vulnerability and risk assessment methods. Specific attention must be addressed to Mediterranean low-lying coastal areas.

A first important objective for the international community should be the enhancement of the work done by the consortium PEGASO with the creation of a Mediterranean Knowledge Clearing House with a Spatial Data Infrastructure (SDI). The Knowledge Clearing House should be free of charge for coastal managers and practitioners to retrieve regional and local scientific data on climate and non-climate related impacts.

5.4 Summary

The most relevant elements issued from the overview of existing coastal vulnerability and risk assessment methods can be summarised as follow:

- Existing methods very rarely include non-climate drivers and do not consider at all interactions between climate and non-climate drivers.
- Methods must carefully consider the spatial resolution or scale of application; that must be compliant with the nature of the hazard to be assessed and related importance of data availability.
- Methods should represent a decision support tool for ICZM and for coastal planning and in this sense they must produce "synthetic" outputs (e.g. risk maps and indicators).

Among the analysed methods, only four are fully compliant with the requirements defined for this research. The methods are SimCLIM, Multi-Scale CVI, CVI – SLR and Desyco.

CHAPTER 6. COASTAL RISK ASSESSMENT METHOD

6.1 Introduction

Over the past decades several methods have been developed for assessing vulnerability of coastal zones and risk related to coastal hazards. After the publication of the AR4 (IPCC, 2007), the research on the issues of coastal vulnerability to climate changes was further intensified. Recently, several reports have been published that summarize key methods of coastal vulnerability assessment (McLeod et *al.*, 2010; ETC-CCA 2011; Mahapatra et *al.*, 2013).

At the same time, many efforts have been made for the development of a culture based on the integrated management of coastal areas. The milestone has been the entering into force of The ICZM Protocol in 2011. As already introduced in Chapter 4, in the ICZM Protocol is specifically cited the need for action at national and local levels where coastal communities need to cope with the effects of coastal hazards. As reported by Rochette and Billè (2011): "*the multiplication of ICZM projects (…) the development of relevant scientific and technical studies (…) the organization of a number of conferences, seminars and workshops" has contributed to the creation "ICZM culture" that represents a concrete platform for raising awareness about the need of coastal risk assessment and adaptation to climate and non-climate forcing"*. In the case of this research the main goal is to provide Mediterranean coastal managers with a method for the integrated assessment of risks associated to multiple coastal hazards generated, or exacerbated, by climate and non-climate drivers. This method aims to provide rapid and effective risk maps for decision-making and for the planning and integrated management of coastal zones and for the definition of sound adaptation measures. The method considers climate drivers, sea level rise and marine storms as the most relevant climate related coastal hazards for Mediterranean context, and non-climate drivers such as the acceleration of the urbanization process and tourism development. The areas where present and potential future hazards can happen are named coastal hazard zones. The proposed risk assessment method intends also to define the criteria to identify theses hazard zones and to define the setback areas as an input to coastal planning and management of risk. Various coastal vulnerability and risk assessment methods have been developed from cross cutting methods to specific sectorial methods and from local to global scale (Kaiser, 2007; McLeod et *al.*, 2010; ETC-CCA, 2011). Even if today there is an increased capacity in achieving satisfactory quality of data "*there is a deficit of integrated assessment methods*" (Kaiser, 2007). This mean that, first, it is not sufficient to study only one aspect of the human-environment system but all the different components must be considered and, second, that risk assessments must be interdisciplinary and comprehensive (Beveridge, 2013). An integrated coastal risk assessment method, which integrates social, economic and ecological components, is needed to contribute to efforts of improving risk management including disaster preparedness and adaptation to climate change (Kaiser, 2007). Risk assessment methods do not require detailed climate information generated by models, which is not available for many parts of the Mediterranean, and they do not require to wait until the science of climate “prediction” is more developed to increasing the general resilience of societies to the types of threat that they may be expected to face in the future (Adger et *al.*, 2005).

Coastal risk assessments provide information about the coastal areas where the hazards may occur, the value of existing assets in those areas, and an analysis of the potential risk to people, economic activities, and the environment that may result from hazard events. That is, the identification of the causes of hazards and their effects (Lummen et *al.*, 2012). The main feature of the coastal hazards and associated risks is that they are not constant, but vary over time. There are several existing risk assessment methods; some assess a single hazard, while some are multi-hazard and multi-risk in their approach (Greiving, 2006; Komendantova et *al.*, 2014).

This mean that risk assessment must involve the collection of data about different types of natural hazards to which a particular coastal area is exposed, the effects of past dangers as well as the estimates and calculations of the potential dangers in the future. The decision-making process for the management of risks must therefore be based not only on the current risks, but must take into account potential climatic and human changes.

Most of methods analysed in Chapter 5 are not taking into account the feedback loops that operate between different subsystems and process at various scales, which is a limitation of classical approaches based on the sectorial analysis of the ecological or socioeconomical components. Furthermore existing methods are focused on vulnerability assessment and less on risk assessment. The analysed tools have been designed before 2013 and they mostly refer to the theoretical framework based on vulnerability as defined in AR5 (IPCC, 2007). This aspect can make them difficult to adapt to the new findings emerged in the IPCC’s AR5, which seeks to bring together the two research streams for vulnerability and risk concepts. The proposed method is based on the latest IPCC theoretical framework. This confirms the need to select a methodological approach easily applicable to the current and future theoretical framework on vulnerability and risk.

Another ambitious objective of this research is to provide coastal managers with a coastal risk assessment tool that for its simplicity and flexibility, as well as for its lower costs, can be used both in the northern and southern shores of the Mediterranean. In this sense coastal managers must be autonomous in adapting the tool to their needs, such as adding or removing a specific variable, at any time without having to resort to an external support which in most cases would be costly. To facilitate the dissemination of the tool across Mediterranean countries, with the aim of supporting the necessary measures to adapt to climate change, it is critically important to locate this tool within the existing regulatory framework on coastal policies and existing datasets.

In response to these emerging issues an index based method for coastal risk assessment has been developed.

The Index based method must meet the following requirements:

- It must be built from scratch by integrating the conceptual assumptions underlying the current vulnerability and risk definition;
- It must consider potential climate and human induced changes;
- It must include SLR and integrate other key climate change impacts like Storms' variability in frequency and intensity;
- It must include non-climate drivers like population growth and tourism development which characterize Mediterranean coastal zones;
- It must consider the combined effects of multiple hazards;
- It must integrate ecological, socio-cultural and economic assets in the coastal system considered as a coupled socio-ecological system.

To this aim, Chapter 6 is structured as follows:

- Introduction to the index based approach
- Definition of the coastal risk function
- Definition of the methodological framework
- Selection of variables for the Forcing, Hazard, Vulnerability and Exposure factors

6.2 Why an Index-based method?

To operationalize risk and to create risk profiles the identification and quantification of a set of variables on different scales can be developed (Brooks et *al.*, 2005). The risk index consists of these variables, and through some mathematical combinations an index number is derived for a specific coastal system. An index-based method enables the translation of a complex reality into a single measurement “*by summarising the total number of complex and intangible things at risk either through expert opinions or statistical analysis*” (Kim, 2009).

What most characterizes an index-based approach is its easy application at the local scale, and the ease of adaptation to different scales of interest in general, alongside its low cost and the fact that it is easy-to-use, intuitive and accessible for practitioners as much as for scientists, which is the case with Mediterranean coastal decision makers. The strength of an index-based method can be seen in the ease with which the tool can be applied to different typologies of coastal zones (such as cliffs, beaches or wetlands) modifying the variables that describe the coastal form. One of the most desirable characteristics is the relative ease of data computation necessary for the construction of the variables. However the main challenge, as for other risk assessment methods, is the limited availability and quality of data at the chosen scale of application. Another positive characteristic is that an index-based method can be applied even in a context where there is a lack of financial resources, because it does not require the support of models or software and can easily be spread among decision-makers for the preparation of concrete policies for the adaptation of coastal areas to climate change.

In the field of risk management associated with natural hazards, the index can be customized to meet the specific strategies for risk management. The value of a risk index-based method is also expressed by its ease of application and its strength in terms of communication to the stakeholders (Sniffer, 2012; Downing & Patwardhan, 2005). A further characteristic is the possibility of using the same variables for the construction of risk maps with geo-referenced data on a local scale.

A coastal risk index provides local and national decision makers with an effective management tool, helping them to analyse and understand the risk a coastal area is exposed to through the prioritization of vulnerable areas (McLaughlin and Cooper, 2011), in order to make comparisons with other systems (e.g. among Mediterranean countries), and for communication purposes (ETC-CCA, 2011).

In this sense a coastal risk assessment method based on an Index-based approach seems to be the most appropriate for the aim of this research.

ETC-CCA (2011) makes a distinction between index-based and indicators-based methods. According to ETC-CCA (2011), in index-based methods, vulnerability (or risk) is expressed “*by a one-dimensional, and generally unit less, vulnerability index*” and this index is “*calculated through the quantitative or semi-quantitative evaluation and combination of different variables*”. In the index-based methods vulnerability is expressed by a set of variables characterising the coastal *system and the coastal process (e.g. exposure) and generally these variables are combined into a final synthetic indicator (ETC-CCA, 2011).* On the other hand, indicator-based methods express the vulnerability (or risk) by a set of indicators, considered as independent elements, that characterise key coastal issues (e.g. pressures, state, impacts, responses) without being combined into a final summary indicator (ETC-CCA, 2011). The differences are not very clear and in fact in some cases the indicators are actually combined into a synthetic indicator, which makes the indicator-based method very similar to the index-based method.

In this research we propose an index-based approach with variables combined in a synthetic coastal risk index. In brief an index-based method for coastal risk assessment consists of the following phases:

1. Identification of the coastal area's spatial attributes;
2. Identification of variables to measure each component of the coastal vulnerability and risk, definition and scoring, allocation of weights to risk factors and normalization and classification of variables (Torresan et *al*., 2012);
3. Use of an algorithm for the calculation of the overall risk for each coastal spatial unit, based on the theoretical framework of risk defined by IPCC (2014a);
4. Construction of coastal vulnerability and risk maps.

Despite having several advantages, existing index-based approaches do present some limitations:

- Lack of appropriate data for some areas, which limits variable implementation and narrows the focus of the approach (Birkman, 2007);
- Some of the variables are too simplistic to properly represent the relevant processes for data aggregation and limited data availability (Fussel, 2009);
- The simple numerical method of ranking and combining the variables into an index is unlikely to accurately reflect real coastal processes (Fussel, 2009);
- Lack of a sound conceptual framework (Fussel, 2009);
- Available index-based methods are mainly based on the identification of monodimensional shoreline segments (Torresan et *al*., 2012);
- Most of available index methods adopt a single coastal hazard approach (Torresan, 2012);
- Computation methods are often weak “with a prevalence of additive procedures applied to dimensionless indicators, without the adequate consideration of fundamental issues, such as normalisation effects, internal compensation, weighting and independence of variables” (Giupponi et *al*., 2013)
- Lack of empirical evidence to demonstrate the utility of vulnerability and risk assessment for triggering or facilitating adaptive behaviours (Preston, 2012).

With the findings from the literature in mind, the proposed approach aims to overcome some of these limitations through the methodological caution outlined below:

- Develop a robust theoretical framework based on the most recent IPCC findings;

- Consider the trends of climate and non-climate forcing, measured on historical observed data, as a proxy of future changes;
- Assess the effects of several hazards and their possible interaction on the coastal area in question (e.g. synthesizing the knowledge expressed by the physical models that describe the effect of natural hazards on the coast);
- Use of variables able to effectively represent the complexity of the processes that characterize the coastal system;
- Consider a three-dimensional extension of the coastal zone;
- Use of standard georeferenced database valid for the Mediterranean scale;
- Use of GIS for the conception of coastal vulnerability and risk maps as a decision support to for coastal planning.

6.3 The coastal risk function

The proposed method for the assessment of coastal risk at the Mediterranean local scale is based on an index-based approach dealing with qualitative and quantitative spatial attributes, representing physical-environmental, socio-economic and institutional variables of the coastal system. Risk is generated by climate and non-climate forcing acting on multiple coastal hazards, namely erosion, flooding and saltwater intrusion.

Definition of spatial attributes and selection of variables is carried out on the basis of these relationships (Adger, 2004). For this purpose the method integrates expert judgments and stakeholder preferences "*in order to aggregate quantitative and qualitative environmental and socio-economic variables*" (Torresan et *al.*, 2012). An index-based method is designed to measure and evaluate a large volume of data associated with complex risks to reduce it to a single number.

The main objective of the proposed method is to assess which coastal assets are at risk to multiple hazards and to quantify that risk through different variables synthetized in a coastal risk index that we call Multiple Hazards Coastal Risk Index (MHCRI).

The method is based on a deductive approach that involves proposing relationships derived from theory or conceptual framework. In deductive research, a hypothesis is tested by operationalizing the concepts and collecting the appropriate data to explore the relationship between the measures of these concepts.

The first step is understanding the coastal system, which is being studied, and the main physical and ecological processes involved.

The second step involves identifying the drivers to be considered in the assessment (forcing and hazards), the way they are inter-related, and how they interact with the coastal system.

The third step involves selecting the best possible variables for describing the risk factors and assigning scores and weights.

During this procedure conceptualization takes place, or the identifying of key concepts and the relationships between them, and the research questions and hypotheses are stated.

The proposed index method considers the factors separately: the forcing, the hazard and the existing coastal system in terms of vulnerability and exposure. These factors can be represented by multiple variables, and the choice of good variables is important for the development of a sound risk index (McLaughlin & Cooper, 2011). The application of the method to a real case study should allow the identification and prioritization, in terms of potential risk, of the zones at risk in the considered coastal region and the homogeneous areas, "*which can be considered as homogeneous geographic sites for the definition of adaptation and management strategies*" (Torresan et *al.*, 2012).

The Multiple Hazard Coastal Risk Index (MHCRI) is the product of four factors: the Coastal Forcing factor (F), the Coastal Hazard factor (H*i*), with *i* representing the number of different hazards considered, and the Coastal System represented by Vulnerability (V) and Exposure (E) factors.

As proposed by other indices in scientific literature (Peduzzi et *al.*, 2009; Davidson & Lambert, 2001) risk follows a multiplicative formula as described in the simplified equation:

$$\boldsymbol{MHCRI_i = F * H_i * (V * E)} \qquad (6.1)$$

Initially we define a coastal risk index for each individual hazard. The overall Multiple Hazard Coastal Risk Index is the result of the numerical values associated to each coastal risk index defined for every different hazard. In this way multiple hazards are integrated in one synthetic final index (MHCRI).

The MHCRI is the sum of the *n* different coastal risk index associated to every hazard.

$$\boldsymbol{MHCRI = \sum_i^n CRIi} \qquad (6.2)$$

This research considers the current hazards regardless of whether or not they have been generated in the past by climate forcing. What interests us is to highlight the effect of current forcing and its potential impacts on existing hazards. Risk exists if hazard exists. If we consider that forcing exists then F > 1, and if also hazard exists then H > 1, which means that risk exists if F * H > 1. If F x H > 1, the "coastal system" natural balance changes. We define the no-risk condition if R ≤ 1, which means that F ≤ 1 and/or H ≤ 1 and even the "coastal system" factor CS, defined by

Vulnerability and Exposure, is ≤ 1. If the “coastal system” factor, CS =1 then Vulnerability + Exposure = 1.

The relations between F and H are described in Figure 6.1.

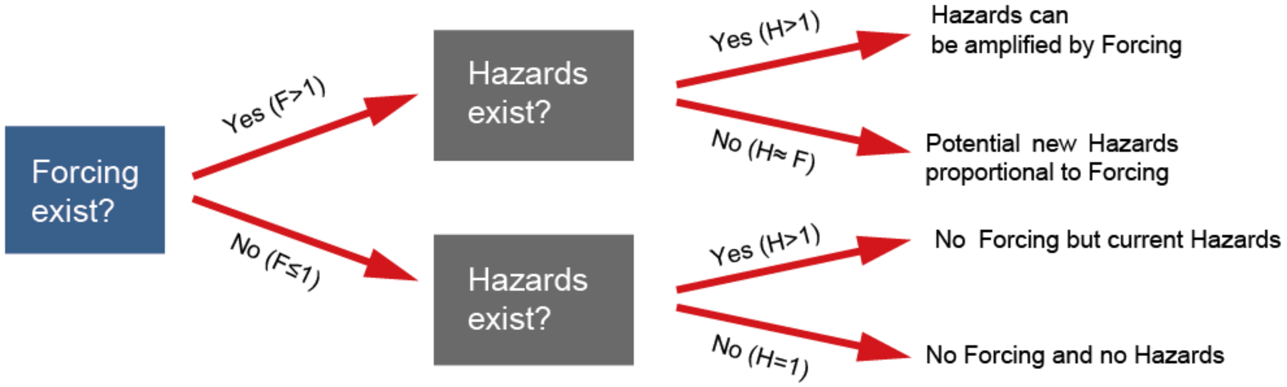

Figure 6.1 Relation between forcing and hazards.

Hence the magnitude of Risk depends on F and H and on the component (E * V).

As we have seen in the previous paragraph, Vulnerability = Susceptibility + Resilience.

Susceptibility (S) and Resilience (R) are two intrinsic characteristics of the coastal system and contribute in different way to the definition of vulnerability:

1) If Susceptibility increases Vulnerability increases;

2) If Resilience increases Vulnerability decreases.

We can conclude that S and E are inversely proportional to V. We can then consider V as a ratio between S and R, **V = S/R**.

The system is not vulnerable when S ≤ R → V ≤ 1;

The system is vulnerable when S > R → V > 1.

The MHCRI equation can be written as follow:

$$MHCRI_i = F * H * (S/R) * E \qquad (6.3)$$

Considering that this research is focused on the Mediterranean coastal areas, the hazards that are taken into consideration are: erosion, flooding and saltwater intrusion.

The MHCRI is the result of the sum of 3 indexes each related to every different coastal hazard. We define the coastal risk indices as follow:

CERI = coastal risk index related to Erosion

CFRI = coastal risk index related to Flooding

SWIRI = coastal risk index related to Saltwater Intrusion

The overall risk index CRI is the mean of the three different indices:

$$\boldsymbol{MHCRI} = \frac{\boldsymbol{CERI+CFRI+SWIRI}}{\boldsymbol{3}} \qquad (6.4)$$

6.4 Methodological framework

6.4.1 Introduction

The methodological framework for the proposed coastal risk assessment method include the following steps:

1. Definition of data sources and spatial attributes;
2. Definition of the hazard zones for erosion, flooding and saltwater intrusion;
3. Definition of the variables for each risk factor associated with each hazard;
4. Representing the variables through a GIS platform;
5. Overlay layers produced through mathematical functions to obtain the final values for each single hazard index and for the multiple hazard index.

The first step is the definition of data sources and the verification of their compatibility with what the method requires. Among them, the cartographic base is of great importance, as it allows the definition of the spatial extent of the study area, which can consist of topographical and geological maps (e.g. 1:25,000 or/and 1:100,000). Another important aspect is the definition of the unit of analysis (the cell) and its dimensions.

The second step is the definition of the so-called “hazard zones” the coastal zones exposed to a specific hazard. In section 6.4.3, we analyse some methods to define the hazard zones and the setback lines to erosion, flooding and saltwater intrusion.

The third and the fourth steps, consist of the selection of proper variables to describe the risk factors (Forcing, Hazard, Vulnerability, Exposure) and the allocation of a score and a weight to each variable. The risk factors are the result of the sum of the relative variables weighted and normalized (Step 5). The Index will be the final result of the multiplication of the value of each factor associated to each coastal “cell” (Step 6).

The process of construction of the index takes place in the following steps, as shown in Figure 6.2 and described in the following paragraphs.

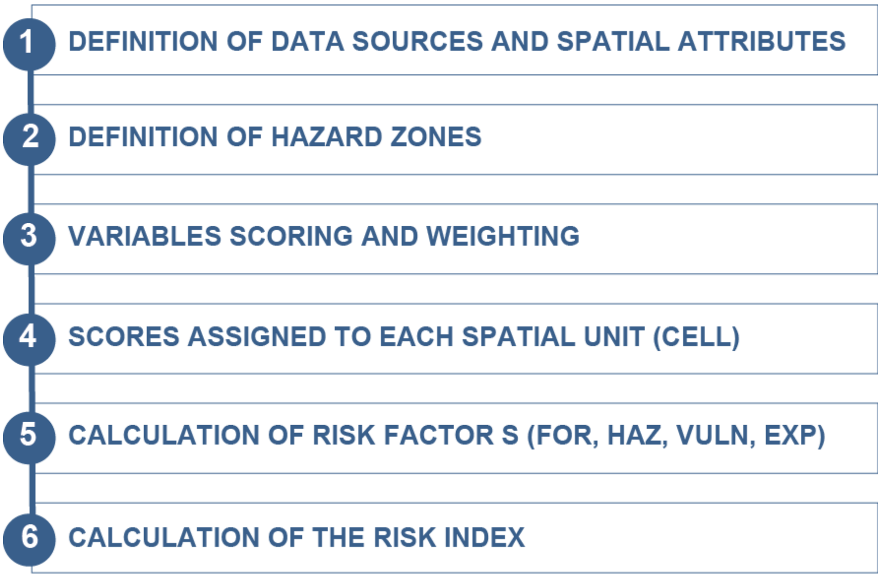

Figure 6.2 Methodology process.

6.4.2 Data sources and spatial attributes

The proposed coastal risk assessment method describes the risks generated by the existing hazard multiplied by a factor of forcing that is represented by the current trends of climate and non-climate forcing. The approach is based on the trends of change actually observed in the Mediterranean, referring primarily to CIRCE project results (Navarra & Lubiana, 2013) for climate factors and to the reports prepared by UNEP-MAP, World Bank, UN-WTO and other international organizations operating in the Mediterranean for non-climate factors. For the ease of application georeferenced databases are needed to simplify the super-imposition of the variables for the calculation of the index factors. The selection of variables is based on existing georeferenced databases for the whole Mediterranean area and on other datasets available at the national or local level.

For this purpose, the methodological framework is built upon the use of a simple and accessible database, such as CORINE Land Cover (CLC). The aim is to select and implement the variables describing the risk factors by means of coastal land use and land cover data. This research presents a GIS approach, based on the use of the CORINE Land Cover (CLC), and other sources of geographical data, aimed at producing several variables for each coastal risk factor (exposure, susceptibility, and resilience) and one synthetic index.

The method developed for this research intends to enable an assessment of the environmental and socio-economical state, at territorial scale, starting from an easy accessible land use dataset. The Land Use of reference used for this method is CLC, but can easily be adapted to other land cover/land use classification systems like PEGASO Land Cover (PLC) (Ivanov et *al.*, 2013; Gardi et *al*., 2002).

CORINE was initiated by the European Union in 1985 and taken over by the EEA in 1995 (EEA website). CLC databases are available for the years 1990, 2000 and 2006 allowing a temporal comparison for a 100m x 100m spatial resolution. The CLC data is available for the following countries: Portugal, Spain, France, Italy, Malta, Slovenia, Croatia, Bosnia, Montenegro, Albania, Greece, Cyprus and Turkey. For the remaining countries (Lebanon, Palestine, Israel, Syria, Jordan, Egypt, Libya, Tunisia, Algeria and Morocco) the PEGASO Land Cover will soon be available (an extension of CORINE Land Cover methods to the rest of the Mediterranean and the Black Sea).

For PLC, maps were produced for the years 2000 and 2011, at 250x250m resolution, and classification nomenclature was designed for producing land accounts (Ivanov et *al.*, 2013). The CLC database is particularly useful in defining the exposure factor of the risk function, as we will see in the next paragraphs. Adopting an approach substantially based on land cover data, the first question concerns data spatial resolution. The resolution itself isn’t enough to determine whether the information needed for the assessment is good enough or not. To answer this question we must understand if the data of the land cover are good enough to describe the information we need for the variables of risk factors (exposure, susceptibility and resilience). Given that one of the objectives of the proposed coastal risk index is the cost and ease of application, there is a need to maximise the use of geo-referenced information already available in the Mediterranean context. As we have seen CLC covers the entire European coastline on the northern shore of the Mediterranean while PLC, when it is available after its validation, will cover the countries on the southern shore and the Middle East (Ivanov et *al*., 2013).

The coastal unit proposed for this research is a pixel of 250m x 250m corresponding to the minimum resolution unit of CLC in common with the future PLC database. It's obvious that for applications in areas covered by CORINE LC the use of a spatial resolution of 100m x 100m is suggested, which allows greater detail, and at the same time covers the temporal extension. The land cover module of the CORINE programme allows the production of geo-referenced information, which is consistent and standardized for all countries of the European Union (Willems et *al.*, 2000). For each coastal unit (cell), the dominant type of land cover is attributed. This means that even if in that area there are different types of land cover, just a single code is assigned to represent the dominant land cover (Willems et *al.*, 2000). The CORINE nomenclature comprises five main classes in level 1 (artificial surfaces, agricultural areas, forests and seminatural areas, wetlands and water bodies), which are split in two more detailed levels, level 2 and level 3. As shown in Table 6.1 we have 5 main classes for level 1, 15 classes for level 2 and a total number of 44 different classes for level 3.

Level 1	**Level 2**	**Level 3**
1. Artificial surfaces	1.1. Urban fabric 1.2. Industrial, commercial and transport units 1.3. Mine, dump and construction sites 1.4. Artificial non-agricultural vegetated areas	1.1.1. Continuous urban fabric 1.1.2. Discontinuous urban fabric 1.2.1. Industrial or commercial units 1.2.2. Road and rail networks and associated land 1.2.3. Port areas 1.2.4. Airports 1.3.1. Mineral extraction sites 1.3.2. Dump sites 1.3.3. Construction sites 1.4.1. Green urban areas 1.4.2. Sport and leisures facilities
2. Agricultural areas	2.1. Arable land 2.2. Permanent crops 2.3. Pastures 2.4. Heterogeneous agricultural areas	2.1.1. Non-irrigated arable land 2.1.2. Permanently irrigated land 2.1.3. Rice fields 2.2.1. Vineyards 2.2.2. Fruit trees and berry plantations 2.2.3. Olive groves 2.3.1. Pastures 2.4.1. Annual crops associated with permanent crops 2.4.2. Complex cultivation patterns 2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation 2.4.4. Agro-forestry areas
3. Forests and semi-natural areas	3.1. Forests 3.2. Shrub and/or herbaceous vegetation associations 3.3. Open spaces with little or no vegetation	3.1.1. Broad-leaved forest 3.1.2. Coniferous forest 3.1.3. Mixed forest 3.2.1. Natural grassland 3.2.2. Moors and heathland 3.2.3. Sclerophyllous vegetation 3.2.4. Transitional woodland shrub 3.3.1. Beaches, dunes and sand plains 3.3.2. Bare rock 3.3.3. Sparsely vegetated areas 3.3.4. Burnt areas 3.3.5. Glaciers and perpetual snow

4. Wetlands	4.1. Inland wetlands 4.2. Coastal wetlands	4.1.1. Inland marshes 4.1.2. Peatbogs 4.2.1. Salt marshes 4.2.2. Salines 4.2.3. Intertidal flats
5. Water bodies	5.1. Inland waters	5.1.1. Water courses 5.1.2. Water bodies
	5.2. Marine waters	5.2.1. Coastal lagoons 5.2.2. Estuaries 5.2.3. Sea and oceans

Table 6.1 CORINE Land Cover classes. (Source: CORINE)

The 44 classes of CORINE capture a large amount of land cover diversity (Willems et *al.*, 2000) but unfortunately not enough to satisfy all the georeferenced data needed for this research. In terms of the variables needed to characterize the exposure factor, for example, there is a lack of information concerning groundwater, essential for the saltwater intrusion hazard. To define the susceptibility factor, geomorphological and/or geological georeferenced maps are needed in order to define the physical characteristics of the coast. The resilience factor (see Section 6.7.2) requires physical-environmental, socio-economic and political-administrative information. The information, not available on existing databases, must be gathered and georeferenced for each pixel of the studied area. The extension of the analysis and application of the index is restricted to the area of influence of each hazard and represents the overlay of all the areas of influence of the multiple hazards that we define "coastal hazard zones" and which is presented in section 6.4.3. Much of the information collected to define the factor "resilience" should be collected directly in situ, for example through questionnaires aimed at key stakeholders. The function proposed to calculate the coastal risk index (Equation 6.3) is applied in all the spatial units of the analysis (Torresan et *al.*, 2012) and “*the dimension of the grid cells (pixel) should be selected at the beginning of the assessment, based on the purposes of the analysis and on the spatial resolution of available data*” (Torresan et *al.*, 2012).

6.4.3 Definition of boundaries: the coastal hazard zones

The most common hazards (erosion, flooding and saltwater intrusion) occurring in the Mediterranean coastal areas and their interaction with forcing were analysed in Chapter 2. 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 integrated approach proposed for this research intends to provide a simultaneous analysis of the effects of multiple hazards in the coastal area under consideration. According to Ramsay (2012) coastal hazard zones "*are used to describe the present and potential future coastal hazard for a particular area*". 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 research, 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 last 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. 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.

One of the first definitions for coastal setback to natural hazards is the one proposed by Healy (1993) "*a line on the ground beyond which, on the balance of evidence, and in the light of scientific knowledge of the moment, it would be prudent to restrict (not necessarily completely avoid) development*". According to the authors of the ICZM Protocol identifying the setback areas has two main objectives:

- To protect an area of ecological and landscape interest, which is very fragile, in the land - sea interface,
- To prevent natural risks resulting from the rise in sea levels related to climate change.

We define a coastal hazard zone for every single hazard considered for this research. The overlay of the different hazard zones generates the coastal multiple hazards zone. The areas of the coastal zones affected by the impacts associated with the three hazards can differ substantially.

In terms of the best scientific method to identify the coastal hazard zones, there is no specific definition in the scientific literature. Nevertheless, there are some operational definitions developed in the technical literature and related to the needs of coastal planning, especially in Australia and New Zealand (Ramsay, 2012; Tonkin & Taylor LTD, 2004). For saltwater intrusion hazard the hazard zone is represented by the entire aquifer at risk of saltwater contamination.

We present now some operational definitions for the three different coastal hazard zones:

- Coastal Erosion Hazard Zone (CEHZ)
- Coastal Flooding Hazard Zone (CFHZ)
- Saltwater Intrusion Hazard Zone (SWIHZ)

Coastal Erosion Hazard Zone - CEHZ

In technical literature there are some operational definitions for Coastal Erosion Hazard Zone (CEHZ). For the purpose of this research we adopt the definitions proposed by Tonkin and Taylor LTD (2004) developed in New Zealand and applicable to soft shores (e.g. gravel and sand beaches) and hard shores (e.g. cliffs). The width of the hazard zones, Hz, is defined with simple formulas as follow.

Hazard zone width for beach shores

Hz = ST + SE + DS + SI + LT

Where:

ST = Horizontal short term fluctuations (m), equal to two times the standard deviation of annual shoreline movement at each profile measured 1 m above the MSL

SE = the shoreline response to storm erosion (m), equal to the standard deviation of annual shoreline movement at each profile measured 1 m above the MSL

DS = distance from above 1 m above MSL to the active dune beach effectively the width of the existing sub aerial beach which is assumed to remain constant in width even with on-going shoreline retreat

SI = the magnitude of shoreline retreat due to possible accelerated sea level rise based on a modified Bruun's rule approach excluding allowance for local relative sea level rise change due to tectonic activity

LT = the long term rate of horizontal shoreline movement (m/y) taking into account abrasion, cross-shore and long-shore losses based on the greater of the long term trend of beach profile data or inferred by expert judgement from aerial photographs.

To provide sufficient time scale for coastal planning the hazard zone for beach shores is considered on a 100-year horizon and appropriate factors of safety are incorporated into each individual component of the equation (Tonkin & Taylor LTD, 2004). The complete methodology to calculate Hz can be found in Tonkin and Taylor LTD (2004).

Hazard zone width for hard shores

Hz = 2 H + (LT x T)

Where:

H = the height of the cliff about its toe

LT = the long term horizontal shoreline movement (m/y) as determined by the expert opinion, based on site inspection and a comparative review of historic and recent aerial photographs

T = planning time period (100 years)

As well as for the beach shore the complete methodology to calculate Hz for cliff shores can be found in Tonkin and Taylor LTD (2004).

Coastal Flooding Hazard Zone - CFHZ

In terms of the sources or drivers, coastal inundation is rarely caused by one factor alone, and is normally due to some combination of tide level, storm surge and wave conditions (and in certain cases is exacerbated by river or land drainage contributions or coastal erosion). These factors are typically correlated in some way but very rarely does an extreme high tide level coincide with both high storm surge and high wave conditions. Having an appreciation or understanding of how these different drivers can combine in a statistical sense is important in assessing coastal flooding.

Waves contribute to coastal flooding hazard by three consecutive processes (MfE-NZ, 2008):

- Wave set-up – after incoming waves break, the average level of the water inside the surf zone to the beach is set up higher than the sea level offshore from the breaker zone
- Wave run-up – the extra height that broken waves reach as they run up the beach and adjacent coastal barrier (natural or artificial), until the wave energy is finally expended by friction and gravity
- Overtopping – the spill-over of waves as they reach the crest of the coastal barrier or defence structure, resulting in flooding of the land and properties behind the barrier.

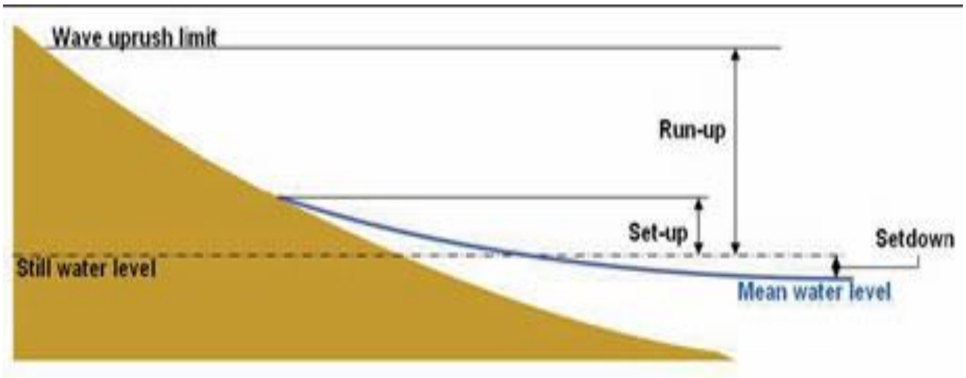

Figure 6.3 Wave set-up, run-up and overtopping. (Source: MfE-NZ, 2008)

At the shoreline, the maximum vertical elevation reached by the sea is a combination of the wave set-up that is induced landward of the wave breaking zone and wave run-up (or swash). These act on top of the storm-tide level. Wave run-up is highly variable even over a short length of coast, varying according to the type of beach, the beach slope, the backshore features and presence of any coastal defence structure. A linear formula to calculate the inundation level, Extreme Inundation Risk Zone (EIRZ), is proposed by Tonkin and Taylor LTD (2004) for New Zealand coastal areas:

EIRZ = MHWS + SLF + SS + SU + SLR2100 + RU

Where:

MHWS = Mean High Water Springs, is set a constant value of 11 m

SLF = Sea Level Fluctuation, is set a constant value of 0.2 m to account for fluctuation in sea level over periods greater than 6 months

SS = Storm Surge is set a constant value of 0,9 m, based on the assessment by Bell et al. (2000) that a storm surge of 0,9 is likely to have a return period of 80 to 100 years

SLR2100 = Sea Level Rise to 2100 calculated using the Bruun rule

SU = maximum wave set up calculated using methods in Part II, Chapter 4 of the Coastal Engineering Manual[14]

RU = Wave Run Up is 70% of Significant Wave Height (MfE-NZ, 2008)

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[14] Coastal Engineering Manual - http://smos.ntou.edu.tw/CEM.htm (accessed June 10, 2014)

A common methodology for the definition of the setback line for coastal protection in Europe and in the Mediterranean is proposed in the CONSCIENCE project (Sanò et *al*., 2008; van Rjin, 2010). The identification of distance for erosion and inundation physical processes is calculated as follows:

1. Identify the maximum erosion during extreme events with a certain return period (e.g. 50 year), with special attention to climate change trends (EXT)

2. Add the sea level rise worst-case scenario under IPCC projection (SLR)

3. Add erosion rates based on scientific and historical information (ERO)

4. Add an uncertainty buffer, typically 10% in civil engineering

The identified distance for physical processes (DPP) is therefore:

DPP = EXT + SLR + ER0 + Uncertainty buffer

According to van Rijn (2010) typical values for DPP are between 50 and 100m, but can be extended to kilometres in the case of low land and coastal plains and in the case of rocky coasts the DPP can be easily reduced in the absence of wave overtopping. In this formula the effects of wave set up and wave run up are not taken into consideration. These two methods consider the hazard zone width, the setback line, and a combined effect of SLR erosion and extreme storm events. What is missing in these formulas is the inland penetration factor. The inland penetration of coastal flooding is the distance in meters reached by a wave given its run-up and given the inland characteristics. The equation of Hills & Mader (1997), developed for Tsunami events, defines the inland penetration Xmax. We propose the equation here, revisited and applied by Pignatelli et al. (2008) to extreme waves' inland penetration.

$X_{\max} = \frac{Hs^{1,33}}{n^2} * k$

Where:

- Hs is the wave run-up
- n is the Manning roughness number of the terrain over which the water surges. Here n varies from about 0.015 for very smooth terrain (e.g., mud flats and ice) to 0.070 for very rough coast areas (dense brush and trees and coarse lava formations). Developed areas typically have n= 0.030 – 0.035 (Hills & Mader, 1997)
- k is a constant number proposed equal to 0.06 for many tsunami (Bryant, 2001)

When the extreme wave impacts the shore, the maximum distance to which it surges inland (Xmax) depends on the maximum water level at the shoreline (the run-up height), the slope of the shore away from the coast, and the roughness of the ground that the water moves across.

For the identification of the flooding hazard zone we need to consider the maximum water level at the shoreline resulting from extreme wave conditions (100-years Return period) and extreme SLR. The inland penetration of this maximum water level is calculated through the Pignatelli et al. (2008) formula. The Flooding Hazard Zone begins from the upward limit of the erosion setback line that will represent the new shoreline as defined for the Erosion Hazard Zone. We must now define the total water height (TWH) under extreme conditions. With this purpose we propose the following formula including all the potential contributors to the

TWH = SLR100 + SS + RU + FI + U

Where:

SLR100 = Global sea-level rise in cm by the year 2100 as projected by the IPCC AR5. As introduced in previous chapters we adopt a precautionary level of SLR = 1,5 m.

SS = Storm surges measures for 100-years return period. Measurement can be retrieved from recent studies like for example Conte & Lionello (2014).

RU = Wave Run Up is 70% of Significant Wave Height (MfE-NZ, 2008). For SWH we use the SWHx95p (Pino et *al.*, 2009).

FI = Freshwater Input is the rainfall height ahead of a storm surge that can cause river levels to rise inland from the coast. Once all this water flows downriver and reaches the coast, local water levels especially near deltas and in bays will rise[15]. The freshwater input parameter measures the maximum rainfall height per day with a 100-years return period.

U = uncertainty factor equivalent to 10%.

We can now adapt Pignatelli's formula to calculate the Xmax.

$$X_{max} = \frac{TWH^{1,33}}{n^2} * k$$

Taking into consideration that this value is measured from the setback line upstream of the hazard zones, this means that the hazard zones for flooding is designed by the upper limit of the erosion hazard zones plus the distance Xmax:

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[15] NOAA - http://www.nhc.noaa.gov/surge/surge_intro.pdf (accessed August 4, 2014)

$$CFHZ = CEHZ + Xmax$$

Saltwater Intrusion Hazard Zone - SWIHZ

The affected area is represented by the coastal aquifers potentially affected by saltwater intrusion and it may extend for several kilometres from the shoreline.

The overall multiple coastal hazards zone is the result of the overlay of the three hazard zones.

$$CMHZ = CEHZ + CFHZ + SWIHZ$$

6.4.4 Selection of variables, scoring and weighting method

The final coastal risk index results from the aggregation of selected variables to generate each risk factor (forcing, hazard, exposure, and vulnerability) and from the final combination of the risk factors. The variables describing the factors can be expressed both in qualitative and quantitative form and can be available at different scales and expressed in different units of measurement (McLaughlin & Cooper, 2010). One of the most important questions concerning an index-based method is the allocation of scores to the different variables. Variables are not all equally important and scoring should be given to each risk factor to reflect its importance in terms of contribution to the estimated overall risk. For this reason it is a common practice to assign a rank to each variable to indicate its contribution to risk (McLaughlin & Cooper, 2010). As discussed by Cutter et *al.* (2000) and Kienberger et *al.* (2009), ranking variables is a critical aspect since data on verification of disasters is not available for multidisciplinary approaches. For the coastal risk index proposed in this research a scale of 1–5 is chosen (Gornitz, 1990; Oziurt, 2007; McLaughlin and Cooper, 2010; Torresan et *al.*, 2012), with 5 contributing most strongly to risk and 1 contributing the least. The proposed scale from 1 to 5 is used for every variable and enables the standardization of the scoring system and the variables expressed in different units to be combined mathematically (McLaughlin & Cooper, 2010).

The scoring methodology is a form of multi-criteria decision analysis (MCDA). MCDA represents a technique with the objective of providing a ranking of alternatives, from the most preferred to the least preferred, based on set of criteria (Sahin, 2011). MCDA techniques provide a modelling framework for aiding complex decision-making processes involving multiple criteria, goals, or objectives of conflicting nature and usually by the means of a weighting method (Sahin, 2011). MCDA techniques are "*commonly used to integrate expert and decision-maker knowledge in* *scoring and weighting exercises*" (Torresan et *al.*, 2012). The scoring-weighting method generally involves the identification of the variables that are relevant to the scope of the assessment. The giving of a score to different variables is a subjective exercise, and the method by which they are ranked must be clearly defined (McLaughlin & Cooper, 2010). Experts or decision makers, reflecting on their views, generally attribute the allocation of scores through the allocation of numerical values to judgements.

For the construction of the variables, we proceed depending on the scope of the variable, the complexity of data and the level of information available in the scientific literature. Table 6.2 describes the methods of scoring used for each factor.

Risk factor	Scoring method
Forcing	Scientific Literature
Hazard	Scientific Literature and Expert Judgement
Exposure	Expert Judgement
Susceptibility	Scientific Literature and Expert Judgement
Resilience	Expert Judgement and Stakeholders involvement

Table 6.2 Scoring method for each risk factor.

With regards to the Forcing and Hazard factors, firstly we need to define the variables that best represent the physical phenomenon and then attribute the scores. The type of knowledge required for scoring these variables demands scientific and technical expertise. Once the variables for forcing and hazard are selected, the values and the scores are assigned according to the current scientific literature.

The forcing factor is what triggers the hazard process or what exacerbates the existing hazards. For the purpose of risk assessment it is important to understand how present and future scenarios of forcing are able to multiply the effect of existing hazards acting on the coastal system.

For example SLR measurements at the local scale represents one of the most challenging issues for the implementation of a coastal risk assessment method. SLR measurements from satellites only became available in 1993 and past measures relied mainly upon tide-gauges (Ulbrich et *al.*, 2013). For the Mediterranean, the mean SLR is the synthesis of sea level measurements from various locations where historical tide gauges records exist. Mediterranean coastal regions show differing behaviour and local measurements are needed (Tsimplis et *al.*, 2009). Nevertheless local SLR measurements are not available for many coastal regions of the Mediterranean so we need to define a scale of variability based on the existing records and related models. We do not consider the Land Subsidence component for the Forcing factor as we assume that is already integrated in the SLR measurement. In this sense it is possible to define a minimum and maximum value for Mean SLR and create a scale from 1 to 5 ranging between the two extreme values.

The expert judgement process of deriving scores and weights covers the following stages:

1. Identify the relevant variables that need to be ranked for the risk evaluation process;
2. Define a clear linguistic to score the variables in terms of risk intensity;
3. Identify the most adequate experts for the scoring process;
4. Assign a different weight to the experts judgement based on their specific expertise (e.g. 1 if they express a judgement on their matter of competence, < 1 if they express a judgement in the same field of knowledge but in a different matter, < 0,5 if they express a judgement in a different field of knowledge);
5. Calculate the weighted scores;
6. Test the results for robustness;
7. Interpret the results.

The integration of expert judgement is particularly important for the allocation of scores to physical, natural and ecological parameters (i.e. pathway and susceptibility factors) and the role of a decision maker is fundamental in the evaluation of socio-economic parameters (i.e. value factors). According to Giove et *al.* (2009), the expert judgements should have a sound scientific and technical basis. The expert's opinion, based on some scientific competence, can be used to assign scores to the physical, natural and ecological variables and for the socio-economic where the views of decision makers become more significant (Torresan et *al.*, 2012). In real terms it is difficult to make such a clear-cut distinction.

The choice between experts, decision makers and other individuals for assigning scores to each variable depends very much on the scale of application of the coastal risk assessment method. In the case of application of the method at the local level, it is necessary to take into account local decision-makers, not necessarily scientists. Expert judgement is used to integrate evidence into evaluation of risks (IPCC, 2014a). Furthermore it is important to consider that expert judgement is particularly important in situations of uncertainty and data scarcity, such as risk and vulnerability assessments (Giove et *al.*, 2009).

In the case of the coastal risk index, the first assignment of scores must be consistent for the whole Mediterranean context. When implementing the Index at the local level, it may be necessary to identify local experts to refine the scores and adopt another weighting approach to integrate the relative value of a local expert judgement. The methodological choice made for the initial definition of the scores assigned to the variables of the coastal risk index is based on a panel of thematic scientific experts, mostly university professors or researchers. For the variables that define the exposure factor we use expert judgement.

6.4.5 Use of GIS to compute and represent the variables

The values identified for each variable are associated to each coastal spatial unit of coast through the realization of a GIS. The software used is ARCGIS 10, which allows the treatment of the data processed in the definition of variables and the comparing and overlapping of them to build layers that represent the single factor (e.g. exposure) or in an associated manner (e.g. by multiplying the values of factors associated to each cell) to calculate the index for a specific hazard or for the multiple hazards index Each parameter acquired with ARCGIS is converted to two-dimensional objects (polygons), geo-referenced in the same reference system and to the same scale, in such a way that it can perform the processing necessary for the determination of the factors that characterize the risk. The set of two-dimensional objects that represent the variable is associated with the attribute table, which is a table in which there are two fields (field), a field “class” that represents the classes of the variable, and a field “score” that represents the scores associated with classes. Each variable is thus represented by a set of polygons, each of which is associated with a record, or a pair of values, one for the class field and one for the score field.

The first step consists of assigning a weight to each variable. Weights are established on an empirical basis or on the basis of expert judgement as seen in the previous paragraph. Risk factors are calculated as the sum of the variables with their relative weights for each significant coastal unit. The significant coastal unit is an area of appreciable size, which makes the effects of each variable meaningful. For the Index developed for this research we consider a coastal unit equal to a 100m x 100m cell to be significant if the coastal zone is covered by CORINE LC, or a square of 250m x 250m if the coastal zone is covered by PEGASO LC.

With ARCGIS the calculation of each component of the risk factor is made very easy by the appropriate geographical forms, which allow both the subdivision of the area in a grid composed by cells, and the application of simple equations such as addition or multiplication.

To calculate the value of each risk factor ($FACT_{RISK}$) of the coastal zone, we apply the equation 6.5 to each significant coastal unit of the study area.

$$FACT_{RISK} = w_1V_1 + w_2V_2 + w_3V_3 + \ldots + w_nV_n \tag{6.5}$$

Where $FACT_{RISK}$ is one of the 4 risk factors (FOR, HAZ, VUL, EXP), (w_1,..,w_n) are the weights of its variables and *n* is the total number of variables.

Equation 6.5 expresses the risk factor as the sum of the products of the weights for the relative scores of the variables. For a significant coastal unit, we intend an area with a specific size as to make the distribution of the classes associated with each variable meaningful. As mentioned previously, a coastal unit is considered significant if equal to that of a square with side length of 100 meters. With ARCGIS, the calculation of the individual factors that characterize the risk is made very simple through appropriate modules, which allow both the subdivision of the area into the above significant units and the application of equation 1. The previous steps have therefore allowed us to process the variables according to the vector format data, which does not allow an immediate comparison. It is necessary that the parameters be conveniently converted to the raster format of the data, generating the raster maps, which allow their immediate comparison. The area of interest is divided into square cells of sides of 100m x 100 m, resulting in a grid of cells (GRID) equivalent to an array *r x c* (r number of rows, c number of columns). Each cell is identified by two indexes, one row and one column, which are the coordinates of the same cell within the grid. This conversion of data format is applied to all the variables for each risk factor, so that a cell with coordinates (h, k) within a raster map corresponds to the same cell in the map of any of the other parameters.

The equation 6.5 becomes:

$$FACT_{RISKij} = w_1V_{1ij} + w_2V_{2ij} + w_iV_{3ij} + \ldots + w_nV_{nij} \tag{6.6}$$

With (i, j) coordinates of the cell, $FACT_{RISKij}$ value of the risk factor on the cell (i,j), (w_1,.., w_n) weights, and (V_{1ij},.., V_{nij}) parameters related to the cell (i,j).

Equation 6.6 is applied to each cell in the GRID, obtaining a different value of the factor analysed for each of them (Overlay Mapping). To obtain the final index we proceed in the same way by multiplying all the factors of risk.

6.5 The Forcing factor

The decision-making process in risk management is often based only on the current risks. One of the most relevant objectives of the proposed coastal risk assessment method is to take into account potential climatic and human based forcing, integrating the measurable trend of changes into the risk function (e.g. SLR trend expressed in mm/y observed through historical series).

The climate forcing is characterized by SLR and by Storms (considered as the changes in intensity and frequency of marine storms).

The factor F is than given by:

$F = F_{Climate} + F_{Non\text{-}Climate} = SLR + ST + S + HF$

Where:

SLR = Sea Level Rise; ST = Storms; HD = Human induced forcing.

The Human induced forcing for the Mediterranean coastal zones can be divided into two separate variables: urban development and tourism development. The first is shown by the average population growth and the second by tourism arrivals in the coastal areas of study.

HD = Urban Development + Tourism Development

Then

$F = SLR + ST + UD + TD$

In the first approximation, we can establish that the climate and non-climate forcing have an equal weight in forming the forcing factor equal to 25%. We also establish that the final value of factor F ranges between 1 and 4.

If $F = 1$ we assume that there is no forcing on the coastal system. If $F > 1$ then forcing exists on the coastal system.

These weights can be rebalanced according to the specific cases of application. In the cases of poor coastal anthropogenic forcing, climatic factors will be dominant. In contrast, in the cases of lower incidence of climate factors the non-climate ones will prevail.

The scale for F is:

Level of Forcing	Score
High	4
Moderate	3
Low	2
No Forcing	1

Table 6.3 Scale of the Forcing factor.

We now analyse the single variables that describe the climate and non-climate forcing. For a more efficient evaluation of the Forcing factor, we consider a scale ranging from 1 to 5 for each variable. The minimum value 1 expresses a very low contribution to forcing and the maximum value 5, expresses a very high contribution to forcing.

6.5.1 Climate forcing variables

Sea Level Rise (SLR)

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 mm/year or cm/year. Sea level rise rate can be measures in different ways, from historical trends to worst-case scientific prediction (e.g. IPCC scenarios). Characteristics that may impact the expected rate of sea level change can vary at regional, national or local level (NOAA, 2012). Coastal vulnerability and risk assessment method application at the local scale generally use local projections for the SLR variable (Abuodha & Woodroffe, 2010; NOAA, 2012). Local projections are mostly derived from long-term tide gauge records and buoys, which are often called relative rates of sea level change (NOAA, 2012). The choice of data for the SLR variable largely depends on the scale of application of the risk assessment method (e.g. local, national or regional).

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). Sea level records starting from the beginning of the 1900s exist in Marseille, Genoa, Trieste and Venice showing a range of 1.1–1.3 mm/year (Ulbrich 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. Tide gauge records have a longer series of data (more than 100 years) but they are only accurate for the gauge locations. The second research question concerns the need to evaluate whether to use the trends of SLR measured on the basis of time series ,or data produced by the models to estimate future projections at the global level (e.g. 2100). The IPCC projections for Global Mean Sea Level Rise (GMSLR) during the 21st century are the sum of contributions derived from models, which were evaluated by comparison with observations, and semi-empirical models (Church et *al.*, 2013). These projections of GMSLR uniformly affect all coastal areas.

The main objective of the SLR variable, which is a component of climate forcing, is to determine how SLR acts at the level of the coastal area analysed. In this sense we can affirm that the projections of future GMSLR can be considered as an exogenous component to be added at the local level SLR measured trend unless a local, national or regional SLR projections model is unavailable. Satellite altimetry measurements allow the construction of the SLR trend expressed in mm / y. These values are measured for each coastal zone as a function of the spatial resolution of the satellite measures. Topex / Poseidon satellite has a measurement accuracy of 2.5 cm[16]. For the aim of this research we use satellite altimetry that can be easily retrieved from the AVISO website developed by Cnes[17]. Topex/Poseidon satellite altimetry measurements are available for the period 1992-2011. To measure the SLR variable we consider a map with trends in absolute sea level across Europe and the Mediterranean based on satellite measurements retrieved from the EEA website[18] elaborated from AVISO data. Data acquired by Topex/Poseidon (Figure 6.4) shows how sea level in the Eastern Mediterranean basin has risen significantly and how sea level is decreasing in the Ionian Sea[19].

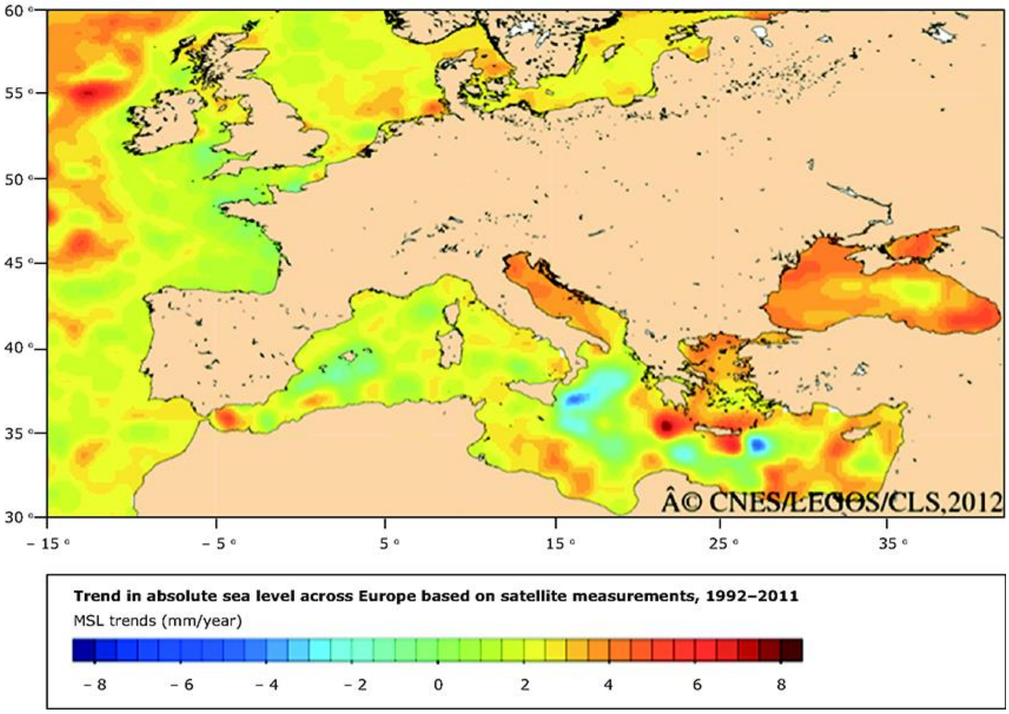

Figure 6.4 Trend in absolute sea level across Europe based on satellite measurements, 1992 – 2011. (Source: EEA website, 2014).

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[16] Earth Observation Portal - https://directory.eoportal.org/web/eoportal/satellite-missions/t/topex-poseidon (accessed October 21, 2014)

[17] AVISO - http://www.aviso.altimetry.fr/en/applications/ocean/mean-sea-level-greenhouse-effect/regional-trends.html (accessed October 20, 2014).

[18] EEA - http://www.eea.europa.eu/data-and-maps/indicators/sea-level-rise-1/assessment (accessed October 20, 2014)

[19] AVISO - http://www.aviso.altimetry.fr/en/applications/ocean/mean-sea-level-greenhouse-effect/regional-trends.html (accessed October 20, 2014)

Another crucial aspect concerns the definition of 1 to 5 classes representing the amplitude of the SLR variable contribution to the forcing factor. We refer to the scale defined by EEA in Figure 6.4. Given that our goal is to define the relative risk for a given level of forcing, measurable at the local level, the minimum value 1 is no sea level rise corresponding to a value ≤ 0. The highest value measured in this scale is 8 mm/y so we assign the value 5 to all trends higher than 6 mm/y.

The intermediate scale is constructed from the two extreme values of minimum and maximum as indicated in Table 6.4.

Level of forcing	Rate (mm/y)	Score
Very High	SLR > 6	5
High	4 < SLR ≤ 6	4
Moderate	2 < SLR ≤ 4	3
Low	0 < SLR ≤ 2	2
Very Low	SLR ≤ 0	1

Table 6.4 Classes of SLR trend (mm/y).

Storms (ST)

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 (e.g. storm surges). The impacts of severe storm events are estimated through the use of a storm intensity scale where "*each storm is associated to a given class in terms of a variable characterising its hazardous potential*" (Mendoza & Jimenez, 2011). Different storm intensity scales exist: the Saffir-Simpson scale for hurricanes (Simpson, 1971; Saffir, 1977), the Dolan and Davis (1992) scale for Atlantic storms. A first classification for the NW Mediterranean was developed by Mendoza and Jimenez (2008) with *the specific aim to be used in a vulnerability assessment context (Mendoza & Ponce, 2011).* An extreme storm can be also defined as an event where *"the wave height exceeds a given threshold during a certain time period" (Mendoza & Jimenez, 2009).* For the objective of this research we consider the SWH as a good proxy by which to measure storm intensity and impacts on the coast (Mendoza & Ponce, 2009; Lionello, 2009: Gualdi et *al.*, 2013). In particular, to estimate the trend of severe storm changes in the Mediterranean we propose to define the Storms variable (ST) as the average number of detected SWH above the 95 percentile / year (SWHX95n). 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 SWHx95n has been plotted for all the Mediterranean (Figure 6.5). The map prepared by Pino is available in one of Lionello's presentations (Lionello, 2009). No other studies on SHWx95n (or SWHx95p) exist for the Mediterranean. As referred by Piero Lionello (email of August 7, 2014) the Pino's study has never been turned into a publication and to find the plotted data is extremely difficult. The values were extracted from a hind cast of waves and show the spatial distribution of empirical percentiles of the distribution. The results of the simulation are still available and should be reworked to provide the required percentile.

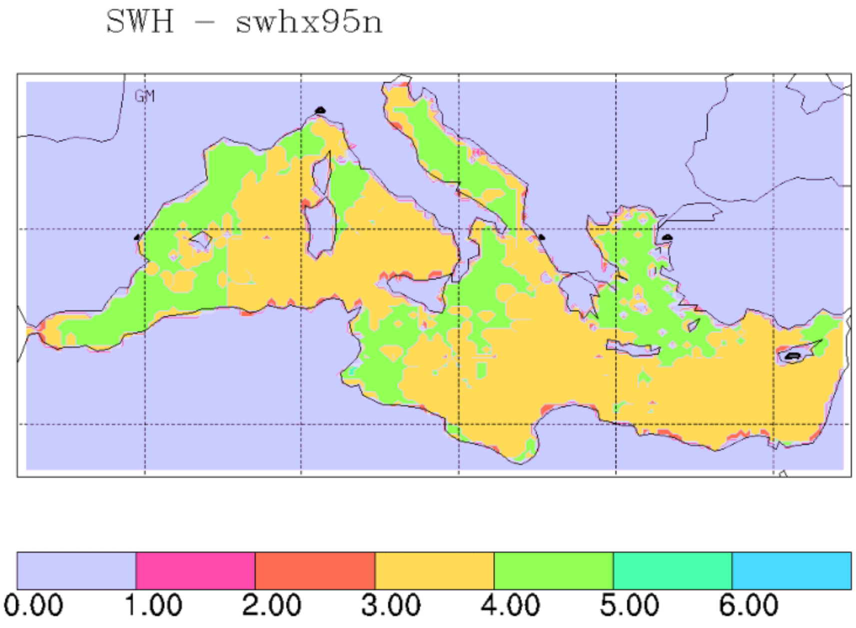

Figure 6.5 Number of detected SWH above 95 percentile. (Source: Pino et al., 2009)

Notwithstanding these limitations, we can use the map prepared by Pino et al. (2009) and extract the SWHx95n classes that represent the Storms trend in the Mediterranean from 1940 to 2002 as indicated in Table 6.5.

Level of SWHx95n forcing	Rate (n/y)	Score
Very High	> 6	5
High	4 < r ≤ 6	4
Moderate	2 < r ≤ 4	3
Low	1 < r ≤ 2	2
Very Low	r < 1	1

Table 6.5 Classes of SWH as a proxy of Storms change (n/y).

6.5.2 Non-Climate forcing variables

The non-climate forcing is mainly related to human development in Mediterranean Coastal zones. To describe the human development factor we adopt two variables: the urban development and the tourism development. The coastal urban development sub-factor represents the trend of human settlements on the coastal strip.

The coastal tourism development variable represents the trend of seasonal use of some Mediterranean coastal areas that leads, in some cases, to a higher use of coastal resources than that of the resident populations. For example in terms of water consumption, a tourist normally uses three or four times as much water as a local resident (Sabban, 2013).

Urban Development (UD)

The variable relative to urban development (UD) can be described through the percentage of coastal population change / year (Klein Goldewijk et *al.*, 2010). The total population of the Mediterranean countries has grown from 276 million in 1970 to 412 million in 2000 (a 1,64 % increase per year) and to 466 million in 2010 (1,35 % increase per year) (UNEP-MAP, 2012). The expected average growth rate per year in the coastal fringe (1995 to 2025) is 0,7 %, with a minimum value of 0,03% per year in Greece and a maximum of 1,5 % per year in Lebanon and Egypt (UNEP-MAP, 2012).

The growth of population on the coastal strip exacerbates the existing hazards and in particular coastal erosion (e.g. new construction and reduction of buffer ecosystems) and saltwater intrusion with the increase of groundwater demand. To define the level of urban development forcing, we use real measures of average population growth both for the southern Mediterranean and for the northern part (Eurostat website).

Both datasets range from 2001 to 2010 as illustrated in Table 6.6.

Country	2001	2010	Average growth /year
Greece	10.934.985	11.183.516	0,23%
Spain	40.476.723	46.486.619	1,48%
France	60.979.315	64.658.856	0,60%
Croatia	4.295.406	4.302.847	0,02%
Italy	56.960.692	59.190.143	0,39%
Cyprus	697.549	819.140	1,74%

Malta	391.415	414.027	0,58%
Portugal	10.330.774	10.573.479	0,23%
Slovenia	1.990.094	2.046.976	0,29%
Montenegro	614.791	618.087	0,05%
Macedonia	2.031.112	2.052.722	0,11%
Serbia	7.504.739	7.306.677	-0,26%
Turkey	67.895.581	72.561.312	0,69%
Albania	3.063.318	2.831.741	-0,76%
Bosnia and Herzegovina	3.789.717	3.844.046	0,14%
Algeria	30.982.000	35.468.000	1,45%
Libya	5.331.000	6.355.000	1,92%
Morocco	29.129.000	31.951.000	0,97%
Tunisia	9.546.000	10.481.000	0,98%
Egypt	68.888.000	81.121.000	1,78%
Jordan	4.910.000	6.187.000	2,60%
Lebanon	3.285.000	4.228.000	2,87%
Syria	16.455.000	20.411.000	2,40%
Palestine	3.285.000	4.039.000	2,30%
Israel	6.131.000	7.418.000	2,10%

Table 6.6 Average growth per year measure in the period 2001 – 2010. (Source: Eurostat website - accessed 9 June, 2014; Hong et *al.*, 2011)

What stands out clearly is the high rate of population growth in the countries of the southern and eastern shores of the Mediterranean, such as Lebanon, Jordan, Syria and Libya. In general, all the countries of the southern and eastern Mediterranean have annual growth rates close to or above 1%. On the northern shores of the Mediterranean, in the countries belonging to the European Union, apart from the growth of Spain (1.48%) and Cyprus (1.74%), other countries have rates below 1%. We divide the different levels of average population growth rate into 5 classes corresponding to the 5 different levels of forcing (Table 6.7).

Level of forcing	Population Average Rate Growth	Score
Very High	ARG > 2%	5
High	1% < ARG < 2%	4
Moderate	0,5% < ARG < 1%	3
Low	0,1 % < ARG < 0,5%	2
Very Low	ARG < 0,1 %	1

Table 6.7 Scores for Human Development forcing.

Tourism Development (TD)

Tourism development is an important human induced driver of change for the Mediterranean basin. If trends from 1990 continue, the Mediterranean Travel Association (META) predicts a more equal balance in the number of tourist arrivals between the northern and the southern shores of the Mediterranean after 2015. This conclusion was reached following analysis of several quantitative variables collected from UNWTO, WTTC, IMF and country sources (Lanquar, 2012). The long-term trend in tourism development in terms of pressure on coastal zones is measured through the relative change of number of arrivals / year. To derive the growth trend in arrivals in the Mediterranean there is series of free data in the World Bank database available on the site: http://data.worldbank.org/indicator/ST.INT.ARVL. We considered data from the year 2000 as it contained all countries up to the year 2012. We do not include countries such as Libya and Syria as they are strongly influenced by the ongoing geopolitical events.

Country	2000	2012	Tourism arrivals increase /year
Croatia	5.831.000	10.369.000	6,49%
France	77.190.000	83.013.000	0,63%
Greece	13.096.000	15.518.000	1,54%
Italy	41.181.000	46.360.000	1,05%
Spain	46.403.000	57.701.000	2,03%
Malta	1.216.000	1.444.000	1,56%
Cyprus	2.686.000	2.465.000	-0,69%
Algeria	866.000	2.634.000	17,01%
Egypt	5.116.000	11.196.000	9,90%
Israel	2.417.000	2.886.000	1,62%
Jordan	1.580.000	4.162.000	13,62%
Lebanon	742.000	1.366.000	7,01%
Morocco	4.278.000	9.375.000	9,93%
Tunisia	5.058.000	5.950.000	1,47%
Turkey	9.586.000	35.698.000	22,70%

Table 6.8 Rate of tourism arrivals increase (n/year).

A time interval of 12 years was considered. In this range we observe very high growth rates for countries such as Turkey, Algeria and Jordan. In general we are witnessing a significant growth in the countries of the southern and eastern shores despite geopolitical instability. The value of Tunisia, for example, is heavily influenced by the Arabic spring, since in 2008 the arrivals were almost 7 million (World bank website, accessed July 2014). The countries of the northern part of the Mediterranean have grown with much lower annual percentages and there are cases such as Cyprus in which there has been a decrease. For the Tourism development variable we also define a set of classes associated with different levels of forcing magnitude.

Level of forcing	Tourism arrivals Average Rate Growth	Score
Very High	ARG > 10%	5
High	5% ≤ ARG < 10%	4
Moderate	1% ≤ ARG < 5%	3
Low	0 % ≤ ARG < 1%	2
Very Low	ARG < 0 %	1

Table 6.9 Forcing classes for Tourism Development variable.

6.5.3 Calculation of the Forcing factor

To calculate the final Forcing factor we need to assign proper weights to each variable. We assign weights in an empirical way, trying to integrate the most relevant characteristics of the area under study. In general terms we assign the same value to each weight (w_{slr}, w_{ss}, w_{hd}, w_{td}) equal to 25% and with $w_{slr} + w_{ss} + w_{hd} + w_{td} = 1$. Each forcing variable (SLR, ST, UD, TD) is a number ranging between 1 and 5, so as we want to express the forcing factor, FOR, as a number which ranges between 1 and 4, we need to divide the sum by 5 and to multiply by 4. The resulting equation is then weighted and normalized.

$$\mathrm{FOR} = \frac{SLR * wslr + SS * wss + HD * whd + TD * wtd}{5} * 4$$

Reported in Table 6.10 are values of “FOR” factor range between 1 and 4. According to the considerations expressed in section 6.3, FOR = 1 is equivalent to a No Forcing state, which means that only existing hazards affect the coastal system. If FOR = 4, the level of forcing affecting the coastal system is very high.

Level of Forcing (FOR)	Score
Very High	FOR = 4
High	3 ≤ FOR < 4
Moderate	2 ≤ FOR < 3
Low	1 < FOR < 2
No Forcing	FOR = 1

Table 6.10 Classes for the Forcing factor.

6.6 The Hazard factor

As mentioned in previous sections, the natural coastal hazards that are taken into account are coastal erosion, coastal flooding and saltwater intrusion (SWI). The purpose of these variables is to describe the natural hazard as a phenomenon in itself. A description of coastal hazards and related impacts on coastal zones is presented in Section 2.6. For every coastal hazard we need to define a scale of intensity attributed in relation to their potential impacts on the coastal system. For computational reasons we consider a scale that ranges between 1 and 4 as described in Table 6.11.

Level of hazard impacts	Score
High impacts	4
Moderate impacts	3
Low impacts	2
No impacts (Equivalent to No Hazard)	1

Table 6.11 Levels of Hazards impacts on the coastal system.

The Hazard factor H, ranges between 1 (No Hazard) and 4 (High Hazard).

The product, F x H, represents the stressor on the coastal system and ranges between 1 and 16. H represents the sum of the effects of the hazards considered. The final score assigned to the factor H is calculated as follows:

$$H = \frac{\sum_{i=1}^{n} Hi}{n}$$

If F x H = 1 there is no forcing and no hazard affecting the coastal system.

Below the variables and the relative scoring for the 3 considered hazards, coastal erosion, coastal flooding and saltwater intrusion, are defined.

6.6.1 Coastal Erosion

The variable chosen to describe coastal erosion is the historical Shoreline Change (SC) that describes the rate of change of shoreline position per year for a specific time span.

The measurement provides information about the long-term behaviour of the coastline. When repeated systematically, it shows where the coastline is retreating (eroding), prograding (accreting) or stable, and, with some simple additional processing, what the rates of change are for each stretch or even cross-shore profile (Martí et *al.*, 2007). This aspect introduces a specificity that is characteristic of the temporal variability of shoreline. In fact depending on natural and human factors the coastline can prograde or retreat. A classic example of accretion is that of a coastal barrier constructed downstream of a beach, with respect to the direction of the dominant current. The transport of sediment will be intercepted by the coastal barrier, creating deposition of sediment upstream, which generates shoreline accretion. The variable and the method of scoring must therefore take into account this variability.

According to a common literature trend, the long-term rates (r) can be grouped into 4 categories (Benassai et *al.*, 2012): high erosion (r > 2.0 m/yr), moderate erosion (1.0 ≤ r < 2.0 m/yr), low erosion (0.5 ≤ r < 1.0 m/yr) and stability (r < 0.5 m/yr). At least two measurements with 5 years of difference between them are needed to compare the position of the baseline shoreline (Martí et *al.*, 2007). The shoreline change factor represents a hazard if there is an erosion state, in the case of accretion the hazard factor must balance the forcing factor. For this reason we have decided to also include values < 1 in the case of accretion (Table 6.12).

Level of coastal erosion impact	Rate of erosion/accretion (m/y)	Score
High erosion	r > 2.0	4
Moderate erosion	1.0 ≤ r < 2.0	3
Low erosion	0.5 m ≤ r < 1.0	2
Stability	- 0,5 ≤ r < 0.5	1
Low Accretion	- 0.5 ≤ r < - 1.0	0,5
Moderate Accretion	- 1.0 ≤ r < - 2.0	0,33
High Accretion	> - 2.0	0,25

Table 6.12 Scores for the erosion hazard factor.

The coastal erosion hazard factor ranges between a minimum of 0,25 and a maximum of 4.

6.6.2 Coastal Flooding

Coastal flooding is generally caused by a combination of high water levels, which may be caused by tides and storm surges, together with waves, which can lead to overtopping of coastal defences and inundation of low-lying areas, potentially causing damage to life and property. We assume that coastal flooding risk exists when the Forcing variable ST > 1.

As introduced in Section 2.3.3, extreme waves and storm surges create the conditions for maximum risk for coastal areas which can be described by indicators such SWHx95p and SLHx95p (Lionello, 2009). We decided to measure coastal flooding using the variable SWHx95p, average number of detected Significant Wave Heights above 95 percentile / year. 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 significant maximum wave (SWH). With the same limitations presented in Section 6.5.1, we refer to the map (Figure 6.6) presented by Lionello (2009) and elaborated by Pino et *al.* (2009).

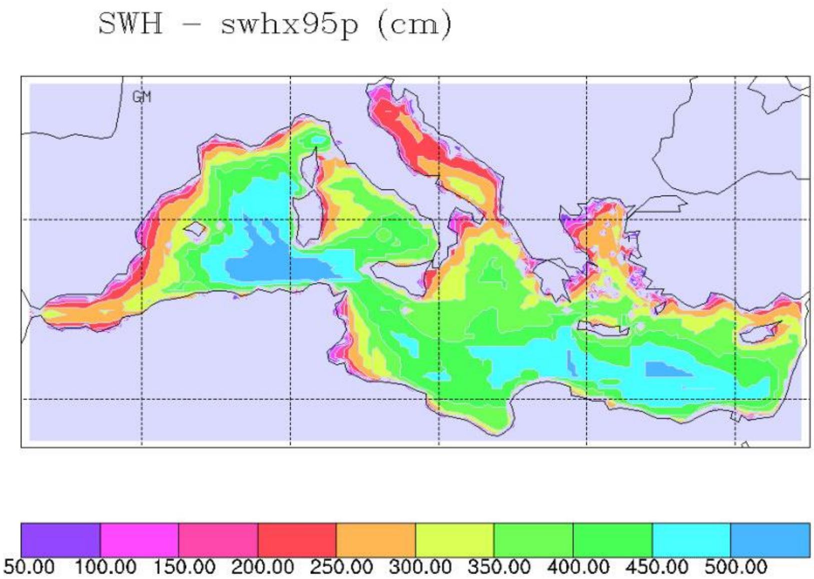

Figure 6.6 Number of events exceeding the long term (e.g. return period Tr = 100 years) 95 percentile of daily significant maximum wave in the Mediterranean. (Source: Pino et al., 2009)

The intensity scale of coastal flooding hazard is elaborated from Figure 6.6. We define the minimum value, corresponding to very low intensity, for values of SWHx95p ≤ 100cm and the maximum value, corresponding to high intensity, for values of SWHx95p > 400cm.

Level of coastal flooding impact	Rate (cm)	Score
High	r > 400	4
Moderate	250 < r ≤ 400	3
Low	100 < r ≤ 250	2
Very Low	r ≤ 100	1

Table 6.13 Scores for the coastal flooding factor.

The coastal flooding hazard factor ranges between a minimum of 1 and a maximum of 4.

6.6.3 Salt Water Intrusion

The measurement of the current Saltwater Intrusion (SWI) situation in coastal zones requires a rather long temporal observation of aquifer changes, including both hydraulic heads and water salinity trends (Dentoni, 2013). Despite several measurement methods being used, (head and water quality measurements, geophysical field campaigns, environmental tracers), the result is that the monitoring of SWI still remains difficult (Werner et *al.*, 2013). SWI hazard represents a forecast of the coastal aquifer situation in a certain period of time (Dentoni, 2013). In this methodology it is proposed that a hazard will be set by identifying areas where salt concentration is higher than a fixed level in relative medium time periods.

The Saltwater Intrusion factor is measured as the rate of horizontal penetration of saltwater edge toe into freshwater coastal aquifers (m/y) where the saltwater edge shows a specific salt concentration level. This need raises two specific research questions: Which concentration level to adopt and how to measure the progress of the salt wedge?

One significant parameter that can be measured is the Chloride concentration. According to Italian Law[20] the maximum level of Chloride concentration for drinkable water is 250 mg/l. We can then establish 250 mg/l as the acceptable threshold that distinguishes freshwater tfrom saltwater. To measure the progress of the salt wedge in the aquifer, it is necessary to obtain measurements of the historical concentration of Chlorides through control wells arranged along the direction of the salt wedge progress. The availability of historical data series for a line of wells located along the coast allows measurement of the speed of salt wedge intrusion inland in the aquifer. The advancement of the intrusion cannot be measured because the intrusion moves linearly in the aquifer as a function of physical parameters.

Considering the problem in 2D rather than in 3D for matters of simplification, one can evaluate the progress of the intrusion in terms of surface over time with unit of measurement expressed in km^2 / y. What we need is to understand the speed of saltwater edge intrusion, measured as the area with chloride concentration higher than 250 mg/l, approximated with the temporal extension of the 2D surface. The increase of surface with chlorides higher than 250 mg/l per year can be considered a good proxy of the advancement of the saltwater intrusion. The surface can be easily measured

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[20] Decreto Legislativo 2 febbraio 2001, n. 31

with GIS. This approximation is done assuming constant boundary conditions (e.g. constant hydraulic conductivity).

To make this variable a useful tool to compare different aquifers we need to standardize the variable to some spatial characteristic of the aquifer. With this aim, we propose to introduce a parameter represented by the ratio between the surface with chloride concentration > 250 mg/l (S_{cl}) and the total surface of the aquifer (S_{aq}).

We apply now a formula to define the speed of the saltwater intrusion that we call SWI_{speed}.

$$SWIspeed = \frac{(Scl)t + n - (Scl)t}{Saq * n}$$

Where n = number of years between the first and the last record of Chloride data.

SWI_{speed} is expressed as percentage of new surface with chlorides concentration > 250 mg/l per year (% of Km2/y).

As there are no data in the literature we suggest indicative values from 1 % Km2 / y for a high level of salt wedge intrusion speed to a value of less than 0.01 % Km2 / y for lower speed.

Level of SWI impact	% of Km2 / y	Score
High	> 1	4
Moderate	0,5 < r ≤ 1	3
Low	0,1 < r ≤ 0,5	2
Very Low	≤ 0,1	1

Table 6.14 Scores for the SWI hazard factor.

The saltwater intrusion hazard factor ranges between a minimum of 1 and a maximum of 4.

6.7 The Vulnerability factor

Vulnerability is defined by the ratio between Susceptibility (S) and Resilience (R). Increasing the resilience decreases the vulnerability of the coastal zone in question. To define values for the Vulnerability factor as a component of the risk function we need to analyse the Susceptibility and Resilience sub-factors.

6.7.1 The Susceptibility sub-factor

IPCC (2012) defines susceptibility as “*the physical predisposition of human beings, infrastructure, and environment to be affected by a dangerous phenomenon due to lack of resistance* …”. For the aim of this research we consider susceptibility as the physical predisposition of the physical-environmental component of the coastal system to be affected by multiple hazards.

For the development of the coastal risk index it is important to define adequate variables in order to represent the most realistic outputs for the coastal zone under assessment. This objective is hard to achieve because there are many variables to be considered to describe the physical processes, and these variables need gathering considerable amount of data (Ozyurt, 2007). The choice of variables is always a trade off between money availability, robustness of the variables to describe the process and time to gather the data. The main challenge is to define good variables to describe the entire process with an acceptable level of uncertainty.

We need to identify good variables to describe the susceptibility of the coastal system to the 3 different hazards: erosion, flooding and SWI. Some of the variables are good enough to describe the susceptibility of the coastal system to more than one single hazard. More in depth considerations must be done for the SWI because susceptibility represents the physical characteristics of coastal aquifers.

The variables selected to describe the susceptibility for each hazard (erosion, flooding and SWI) are specified for each coastal sub-system and ranked from 1 (very low susceptibility) to 5 (very high susceptibility) in Table B1, B2 and B3 of Appendix B. Some variables have the same definition but different meaning if applied to different hazards.

In summary, we have 5 variables for coastal erosion, 5 variables for coastal flooding and 7 variables for saltwater intrusion. Individual susceptibility variables can be weighted to represent the relative importance of each variable. According to Torresan et al. (2012) a guideline with linguistic evaluations supporting experts and decision makers in the assignation of weights is proposed in Table 6.15.

Linguistic evaluation for susceptibility	Weight
Most important susceptibility variable	1
Weakly less important susceptibility variable	0,75
Strongly less important susceptibility variable	0,5
Demonstratively less important susceptibility variable	0,25
Not important susceptibility variable	0

Table 6.15 Linguistic evaluation for weighting susceptibility variables.

For the general definition of the coastal risk index we assume that every susceptibility variable has the same weight in contributing to the overall susceptibility as indicated in Table 6.16. For the application to real case studies local experts and decision makers can be involved in assigning a relative weight to each variable.

Hazard	**Variable**	**Weight**	**Relative value of the variable**
Erosion			
1	Landform	1	1/5
2	Artificial frontage	1	1/5
3	Coastal slope	1	1/5
4	Historical Shoreline change	1	1/5
5	River flow regulation	1	1/5
Flooding			
1	Coastal slope	1	1/4
2	Elevation	1	1/4
3	Distance from the shoreline	1	1/4
4	River flow regulation	1	1/4
Saltwater Intrusion			
1	Groundwater Occurrence (Aquifer Type)	1	1/7
2	Aquifer thickness (saturated)	1	1/7
3	Hydraulic Conductivity	1	1/7
4	Height of Groundwater Level above Sea Level	1	1/7
5	Distance from the shore	1	1/7
6	Impact of existing status of Seawater Intrusion	1	1/7
7	River flow regulation	1	1/7

Table 6.16 Susceptibility variables

The final number associated to the susceptibility, SUSC, ranges between 1 and 5. To obtain the final value of each SUSC*haz* (where *haz* can be *ero*, *flood* or *swi*), a number between 1 and 5, we calculate the sum of the weights variables v*i* and divide each element by the sum then multiply 5 times. Then we multiply the scores by the normalized weight.

$$\text{SUSC}ero = \frac{\sum_{i=1}^{5} vi}{5}$$

$$\text{SUSC}flood = \frac{\sum_{i=1}^{5} vi}{5}$$

$$\text{SUSC}swi = \frac{\sum_{i=1}^{7} vi}{7}$$

The final number associated to the resilience factor, SUSC is still a number between 1 and 5 resulting from the sum of the SUSC numbers associated to each hazard divided by 3.

SUSC = $\frac{SUSCero+SUSCflood+SUSCSswi}{3}$

The level of SUSC classes is reported in Table 6.17.

Level of Susceptibility (SUSC)	Score
Extremely High	SUSC = 5
Very High	4 ≤ SUSC < 5
High	3 ≤ SUSC < 4
Moderate	2 ≤ SUSC < 3
Low	1 < SUSC < 2
No susceptibility	SUSC = 1

Table 6.17 Ranking for Susceptibility (SUSC).

6.7.2 The Resilience factor

As for the factor of susceptibility, to identify the most appropriate variables, we take the definition of resilience according to IPCC (2014a). The resilience component is mentioned by the authors of the ICZM Protocol and is of twofold importance. On the one hand the need to protect and preserve the natural heritage and landscape of the coastal zone and on the other the need to preserve those ecosystems that provide the natural resilience of coastal areas (e.g. sea grass, dunes, etc.).

The variables we select to describe the resilience factor are reported in Appendix B.

For the resilience factor we have 6 variables for coastal erosion, 7 variables for coastal flooding and 7 variables for saltwater intrusion. Referring to Torresan et *al.* (2012) a guideline with linguistic evaluations supporting experts and decision makers in the assignation of weights to susceptibility variable is proposed in Table 6.18.

Linguistic evaluation for resilience	Weight
Most important susceptibility variable	1
Weakly less important susceptibility variable	0,75
Strongly less important susceptibility variable	0,5
Demonstratively less important susceptibility variable	0,25
Not important susceptibility variable	0

Table 6.18 Linguistic evaluation for resilience variables.

For the general definition of the coastal risk index we assume that resilience variables contribute in the same manner to the overall susceptibility value so their weight is 1 (Table 6.19).

For the application to real case studies, local experts and decision makers can be involved in assigning weights.

Hazard	Variable	Weight	Relative value of the variable
Erosion			
1	Ecosystems health	1	1/6
2	Education level	1	1/6
3	Age of population	1	1/6
4	Awareness and Preparedness	1	1/6
5	Hazard maps	1	1/6
6	Coastal protection structures	1	1/6
Flooding			
1	Ecosystems health	1	1/7
2	Drainage density	1	1/7
3	Education level	1	1/7
4	Age of population	1	1/7
5	Awareness and Preparedness	1	1/7
6	Coastal protection structures	1	1/7
7	Risk / Hazard maps	1	1/7
Saltwater Intrusion			
1	Groundwater consumption	1	1/7
2	Age of population	1	1/7
3	Education level	1	1/7
4	Awareness and Preparedness	1	1/7
5	Hazard maps	1	1/7
6	Freshwater Barrier wells	1	1/7
7	Water management	1	1/7

Table 6.19 Resilience variables and relative weights.

We apply the same method as that for susceptibility. The final number associated to the resilience factor, RES, ranges between 1 and 5.

To obtain the final value of each RES*haz*, a number between 1 and 5, we calculate the sum of the weights variables v*i* and divide each element by the number of variables.

RES*ero* = $\frac{\sum_{i=1}^{6} vi}{6}$

RES*flood* = $\frac{\sum_{i=1}^{7} vi}{7}$

RES*swi* = $\frac{\sum_{i=1}^{8} vi}{8}$

The final number associated to the resilience factor, RES is still a number between 1 and 5 resulting from the sum of the RES calculated for each hazard divided by 3.

RES = $\frac{RESero+RESflood+RESswi}{3}$

6.7.3 Calculation of Vulnerability

Both the susceptibility (SUSC) and the resilience (RES) factors values ranges between 1 and 5.

Vulnerability (VULN) is the result of SUSC / RES.

VULN*ero* = SUSC*ero* / RES*ero*

VULN = $\frac{SUSCero+SUSCflood+SUSCSswi}{RESero+RESflood+SUSCswi}$

There are 19 potential combinations between the two factors (Table 6.20) that can be aggregated in 7 different classes as represented in Table 6.21.

		SUSCEPTIBILITY				
		1	2	3	4	5
RESILIENCE	1	1	2	3	4	5
	2	0,5	1	1,5	2	2,5
	3	0,33	0,67	1,00	1,33	1,67
	4	0,25	0,5	0,75	1	1,25
	5	0,2	0,4	0,6	0,8	1

Table 6.20 Potential combinations of SUSC and RES to form VULN.

Combination	**Result**	**Classes**	**Description**
1	5	3 - 5	From moderate to high SUSC and very low RES
2	4		
3	3		
4	2,5	1,66 - 2,5	From very high to high SUSC and low to moderate RES
5	2		
6	1,66		
7	1,5	1,25 - 1,5	From moderate to very high SUSC and from low to high RES
8	1,33		
9	1,25		
10	1	1	Equilibrium
11	0,8	0,66 - 0,8	From low to high SUSC and from moderate to very high resilience
12	0,75		
13	0,66		
14	0,6	0,4 - 0,6	From low to moderate SUSC and from high to very high RES
15	0,5		
16	0,4		
17	0,33	0,2 - 0,33	Very low SUSC and from moderate to very high RES
18	0,25		
19	0,2		

Table 6.21 Vulnerability classes.

Table 6.21 allows the creation of a vulnerability map divided into seven classes. This map is used to represent the seven possible combinations between SUSC and RES. The vulnerability class is assigned to each cell 250m x 250m (or 100m x 100m in case of CORINE LC). The vulnerability map represents the state of the coastal system in the absence of forcing and hazard.

6.8 The Exposure factor

6.8.1 Selection of coastal assets

The Exposure factor, as defined by IPCC (2014a) indicates “*the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected*”. In this interpretation the exposure represents the elements at risk and includes all components within a particular coastal area that may be adversely affected by a hazard, directly or indirectly (Lummen & Yamada, 2014). Exposure generally indicates the degree to which the elements at risk are exposed to a particular hazard (Lummen & Yamada, 2014). In this research, exposure is considered as one of the factors contributing to the risk function.

The exposure factor represents the physical-environmental and socioeconomic elements existing on the coastal area and exposed to hazards. In this sense "*the elements at risk are often referred to as the ''assets'' of a particular area and have spatial and non-spatial characteristics*" (Lummen & Yamada, 2014). For this research we define the elements at risk as "coastal assets". We describe the coastal assets through the use of two groups of variables: physical environmental variables (e.g. species or ecosystems, environmental functions, services, and resources) and socioeconomic variables (e.g. people, livelihoods, infrastructure, or economic, social, and cultural assets). The interaction and relationship between the elements at risk and the assessed hazard defines the exposure (Lummen & Yamada, 2014).

With the aim of simplifying the implementation of spatial data analysis within a framework that immediately allows their operational application, the information to build exposure variables is based on the categories proposed by the CORINE Land Cover. CORINE is currently limited by being valid only for the coastal areas of the European Mediterranean countries. PEGASO Land Cover, using the same CORINE LC classes, will soon cover the eastern and southern shores. The evolution of PEGASO LC confirms the validity of this research based on the use of the existing categories of the CORINE LC database for the identification of coastal assets over the area of the Mediterranean.

The proposed methodology for coastal risk assessment combines information from several indicators in order to create a coastal index associated with single coastal units (250m x 250m pixel) described through CORINE LAND COVER.

To calculate the exposure variables we proceed in this way. Each 250m x 250m cell, corresponding to a pixel of the analysed coastal areas, is associated with a value corresponding to a class among the ones present in CORINE LC database.

To differentiate the coastal asset we split CORINE LC five classes into nine classes: 1) People and Livelihoods, 2) Infrastructures, 3) Industrial or Commercial Units, 4) Socio-Cultural assets, 5) Agriculture, 6) Forest, 7) Seminatural Areas, 8) Wetlands and 9) Water Bodies.

The two main components of the coastal system are covered by CORINE LC classes as follow:

Socio-Economical: People and Livelihoods, Infrastructures, Industrial or Commercial Units, Socio-Cultural assets, and Agriculture

Physical-Ecological: Forest, Seminatural Areas, Wetlands, Water Bodies

Nevertheless not all coastal assets are covered by these CORINE LC classes such as for example tourism activities, livestock and aquifers (in terms of freshwater availability). Considering the importance of these variables, for the aim of the research, we propose to consider also the variables Livestock density index, Tourism structures density, and Presence of aquifers to adjust CORINE attribute where needed.

Livestock density index

The variable is expressed as livestock units per hectare[21]. In the interpretation of the livestock density index, the limits of this theoretical unit are to be taken into account. The livestock species aggregated in the LSU total, for the purpose of this indicator, are: equidae, cattle, sheep, goats, pigs, poultry and rabbits (EUROSTAT, 2014)

Tourism structures density

This can be expressed in terms of accommodation units per km2 (Satta, 2006).

Presence of aquifers

This variable can be represented by the georeferenced hydrogeological map of the area where it is necessary to contour the aquifers' extension also in terms of their fresh groundwater productivity. The evaluation of a Land Cover value can be modified accordingly with an expert judgement on the real use of the coastal analysis unit.

The exposure variables are summarized in Appendix C (Table C.1), which indicates the coastal system component for each variable and the coastal asset at risk related to each hazard.

A coastal asset corresponding to the nine CORINE classes is associated to each coastal system component (physical-environmental and socio-economic). The variables describe the interaction between the hazards and the coastal asset. Considering for example the coastal asset “People and livelihoods”, the possible alternatives proposed by CORINE are: Continuous Urban Fabric or Discontinuous Urban Fabric. If we take into consideration the exposure of the coastal asset “People and livelihoods” to hazards, we need to understand how the hazards will impact the cells represented by Continuous Urban Fabric and Discontinuous Urban Fabric and to assign a score from 1 to 5 to these variables. CORINE describes the variable “Continuous Urban Fabric” as follow: “Most of the land is covered by structures and the transport network. Buildings, roads and

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[21] EUROSTAT - http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/dataset?p_product_code=TSDPC450 (accessed July 20, 2014)

artificially surfaced areas cover more than 80% of the total surface. Non-linear areas of vegetation and bare soil are exceptional" and often represents urban centres. The variable "Discontinuous Urban Fabric" is described as follow "*Most of the land is covered by structures. Buildings, roads and artificially surfaced areas are associated with vegetated areas and bare soil, which occupy discontinuous but significant surfaces*". Buildings, roads and artificially surfaced areas cover between 50 and 80% of the total surface area of the unit (CORINE Land Cover Nomenclature Illustrations, 2014). Given the density of buildings to which correspond a higher density of people living there, we can say that the level of exposure related to soil loss due to erosion or flooding is greater for Continuous Urban Fabric than for Discontinuous Urban Fabric. Nevertheless, it is necessary to use an approach of expert judgement to assign scores to each variable.

6.8.2 Scoring and weighting method for Exposure variables

According to various methodologies applied at the international level (Gornitz, 1990; Abuodha and Woodroffe, 2006; Torresan et *al.*, 2012), the allocation of scores to vulnerability classes is performed using a 1–5 scale. For each analysed coastal asset, this scoring method allows the definition of relative rankings within the subset of risk classes associated with each variable of exposure factor.

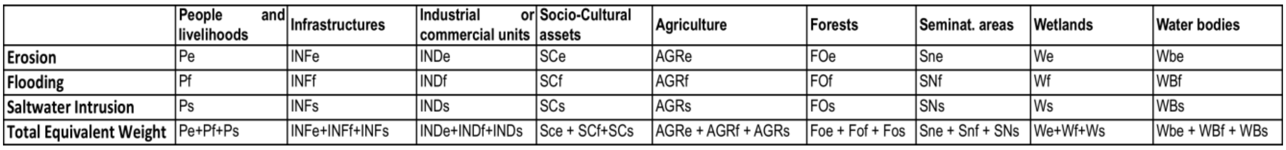
The maximum score 5 is assigned to the most important (i.e. higher) risk class of the coastal asset in terms of its environmental, social and economical value and in the same way the minimum score 1 is assigned to the risk class that is considered the least important (i.e. the lowest risk class) in the subset of classes defined for each indicator (Torresan et *al.*, 2012).

To assign scores to each coastal asset a panel of scientific experts from academia has been created, with 10 experts involved. For every expert we indicate the University or Research Centre, their title and specialization. Each expert was asked to assign a score to each variable representing a coastal asset. The competency of each expert on hazards or on land use is weighted from 1 to 3. The scale of weights is given in Table 6.22.

Level of competency	Weight
Fully competent	3
Partially competent	2
Aware about the subject but no competent	1

Table 6.22 Level of expert's competency.

For experts the final weight is the result of their competency on every hazard (erosion, flooding and saltwater intrusion) and on every land use (People and livelihoods, Infrastructures, Industrial or commercial units, Socio-Cultural assets, Agriculture, Forests, Seminatural Areas, Wetlands, Water bodies).



	People and livelihoods	Infrastructures	Industrial or commercial units	Socio-Cultural assets	Agriculture	Forests	Seminat. areas	Wetlands	Water bodies
Erosion	Pe	INFe	INDe	SCe	AGRe	FOe	Sne	We	Wbe
Flooding	Pf	INFf	INDf	SCf	AGRf	FOf	SNf	Wf	WBf
Saltwater Intrusion	Ps	INFs	INDs	SCs	AGRs	FOs	SNs	Ws	WBs
Total Equivalent Weight	Pe+Pf+Ps	INFe+INFf+INFs	INDe+INDf+INDs	Sce + SCf+SCs	AGRe + AGRf + AGRs	Foe + Fof + Fos	Sne + Snf + SNs	We+Wf+Ws	Wbe + WBf + WBs

Table 6.23 Equivalent weight for Hazard and Coastal Assets

The final weights associated to every coastal asset are normalized with the total number of equivalent weights. In Appendix C (Table C.1) we present the Panel of ten experts involved for this research. We associate an identification number to every expert. A score is attributed to each expert competency for every Hazard and for every Coastal asset.

For every expert is asked to express a score based on the classes defined in Table 6.24.

Linguistic	Level of risk to which the coastal asset is exposed	Score
Most important class	Very high exposure to hazard *i*	5
Weakly less important class	High exposure to hazard *i*	4
Rather less important class	Moderate exposure to hazard i	3
Strongly less important class	Low exposure to hazard i	2
Least important class	Very low exposure to hazard i	1

Table 6.24 Linguistic evaluation supporting the expert in the assignation of scores to exposure factors.

The results are presented in Chapter 8, 9, 10 and the aggregated values in Chapter 11.

6.9 Final calculation of the Multiple Hazards Risk Index

The first step for the calculation of the Multiple Hazards Coastal Risk Index (MHCRI) is to define the extreme values of variability and with this aim we refer to the equation 6.1 (MHCRI = F * H * V * E).

We apply the equation 6.1 to the every mono-hazard Risk index and we calculate the minimum and maximum values of every Risk index (Table 6.25).

Risk Index	**F**	**H**	**V**	**E**	***R = F * H * V * E***	
					MIN	**MAX**
CERI	1 ÷ 4	0,25 ÷ 4	0,2 ÷ 5	1 ÷ 5	0,05	400
CFRI	1 ÷ 4	1 ÷ 4	0,2 ÷ 5	1 ÷ 5	0,2	400
SWIRI	1 ÷ 4	1 ÷ 4	0,2 ÷ 5	1 ÷ 5	0,2	400

Table 6.25 Ranges of Risk Index variability.

The equation to calculate the final value of Risk for multiple hazards (RISK*mh*) is derived from the equation 6.4.

$$\mathrm{RISK}mh = \frac{\mathrm{RISK}ero+\mathrm{RISK}flood+\mathrm{RISK}swi}{\mathbf{3}} \qquad (6.7)$$

Applying equation 6.7 values for Risk to multiple hazards (RISK*mh*) range between 0,15 and 400. With the purpose of capturing the various combinations of RISK*mh* we propose a scale with 8 classes of Risk intensity.

The scale varies from No Risk (RISK*mh* ≤ 1) to extremely high risk (RISK*mh* > 320) (Table 6.26).

The classes defined for Multiple Hazard risk are valid also for Single Hazard risk (Coastal Erosion, Coastal Flooding, Saltwater Intrusion).

Intensity of Risk	**Class**
NO Risk	≤ 1
Extremely Low	1 - 8
Very Low	9 - 36
Low	37 - 54
Moderate	55 - 80
High	81 - 200
Very High	201 - 320
Extremely High	321 - 400

Table 6.26 Scale of RISK intensity.

As we already mentioned in Section 6.4, we need to apply the value RISK*mh* to each cell of the GRID, obtaining for each of them a different value of the final index through the Overlay Mapping.

To obtain the final value $\mathrm{RISK}mh_{\mathrm{ij}}$ for every cell of the GRID we proceed applying the equation 6.7:

$$\mathrm{RISK}mh_{\mathrm{ij}} = \frac{\mathrm{RISK}ero_{\mathrm{ij}} + \mathrm{RISK}flood_{\mathrm{ij}} + \mathrm{RISK}swi_{\mathrm{ij}}}{\mathbf{3}}$$

With (i,j) coordinates of the cell, $\mathrm{RISK}mh_{\mathrm{ij}}$ value of the final risk index to multiple hazards for the cell (i,j).

6.10 Summary

An index-based approach is chosen for the development of a method to assess coastal risk to multiple hazards.

The method developed for this research proposes an integrated risk assessment of coastal zones to multiple hazards, which takes into account the effects of SLR and Storms together with non-climate drivers on natural hazards variability.

The conceptual framework for vulnerability and risk defined in the AR5 (IPCC, 2014a) is applied and operationalized through a Risk function. The proposed method considers Risk as the joint action of climate and non-climate forcing and existing hazards on the existing coastal system described in terms of vulnerability and exposure. Forcing, hazard, vulnerability and exposure represents the risk factors and they are described by multiple variables.

A relevant methodological consideration, which characterizes the proposed method, concerns the definition of the spatial field of application of the coastal risk index. In reference to the provisions of the ICZM Protocol, we propose a methodology to define the limits of the coastal hazard zones and the setback lines for coastal erosion, coastal flooding and saltwater intrusion. The coastal hazard zone, intended as a coastal area where the risk occurs, it also represents the spatial field of application of the method.

The values identified for the variables describing the Risk factors are associated with the coastal spatial units defined for the research through the application of a GIS, which allows the treatment comparing and overlapping variables and to build layers that represent the single factor (e.g. exposure) or an index (e.g. by multiplying the values of factors associated to each cell).

Forcing, Hazard, Vulnerability and Exposure factors are discussed and analysed. For each factor a number of variables is proposed with relative scores and classes.

Finally the methodology to calculate the single hazard risk index (CERI, CFRI, SWIRI) and the multiple hazards risk index (MHRI) is presented.

CHAPTER 7. CASE STUDY: THE GULF OF ORISTANO

7.1 Introduction

The study area identified for the application of the method of risk assessment, established for research, is located in the west coast of Sardinia in Italy. It extends from the south of Capo Frasca, developing north through the coastal arc of the Gulf of Oristano and end on the coastal rock formations of Capo Mannu, for a linear development of about 70 km. The administrative areas concerned included in the Province of Oristano are the coastal municipalities of Terralba, Arborea, Santa Giusta, Cabras and Oristano. The industrial port of Oristano located in the central part of the homonymous gulf, is the main maritime node of the Sardinian western coast. State Route 131 is the main road artery through which to reach Oristano from Cagliari, capital of Sardinias.

The coastal system of the Gulf of Oristano is a low-lying area characterised by the “Bonifica” of Arborea”, reclamation works realised during the fascist period in the 30s, which makes the area particularly vulnerable. Forcing acting on the Gulf of Oristano is mainly represented by Storms. Registered SWH in the western coast of Sardinia are between the most intense in the whole Mediterranean. Saltwater intrusion hazard is already occurring in the coastal zones of Arborea and represents an extremely relevant risk for agriculture and tourism activities of the area.

7.2 Characterization of the area

7.2.1 Climate

Winds regime

The historical data retrieved from the stations of Oristano and Capo Frasca highlight how the whole coastal area is dominated by the winds of the fourth quadrant with greater frequency and intensity determined by the mistral wind[22]. The prevailing winds from the NW and W represent about 50% of the directions detected, while in the southern quadrants winds (Sirocco and South-west winds) constitute more than 25% of the events, with the south winds that in the plain of Oristano reach high intensity, being facilitated by the lack of interference of relief along the channelling on the Campidano plain.

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[22] ARPAS - http://www.sar.sardegna.it (Accessed July 26, 2014)

Sea Level

There are no specific local studies on SLR in the Gulf of Oristano except a recent geo-archaeological study on SLR in some archaeological sites and specifically the ancient roman city of Tharros. The estimation is a sea level rise of 1,29 ± 0,3 m (Antonioli et *al.*, 2010) in the last 2000 years. For a direct measure of SLR the closest Tide Gauges station is Carloforte. The historical data series range from 1988 to 2013. For observed mean sea level change in the western Mediterranean Sea we refer to satellite measurements.

Waves regime

The hydrodynamic regime in the Gulf of Oristano is dominated by the Mistral wind, which blows from the northwest sector, between 300 and 315 degrees, and that represents the main meteorological forcing (Cucco et *al.*, 2006). The consequence of the strong mistral winds acting on a fetch extended to the Gulf of Lion causes a wave of the most intense of the entire Algerian-Provencal basin. The closest Wave Station to the Gulf of Oristano is in Alghero and belongs to the National Wave Observation System. For the station of Alghero are available records for SHW starting from 01-July-1989 to 05-Apr-2008. It is a series of 19 years for which have been measured the following extreme values of SWH.

SWH (m)	Number of events	Seconds
9,0 < SWH < 9,5	3	13,5
8,5 < SWH < 9,0	8	13,5 < t < 15
8,0 < SWH < 8,5	18	12 < t < 13,5

Table 7.1 SWH recorded in Alghero Station.

Temperature

The temperature is mild in winter, the daytime excursion is small (around 7° in winter and 12 degrees in summer), the annual excursion is equal to 14°-15 °, the minimum temperatures are recorded in the winter months with near-zero values only in the cooler hours of the day and rarely for long periods. Maximum temperatures in the summer (July and August in particular) often exceed, during the hottest hours of the day, 35° C.

Rainfall

The average amount of annual rainfall, measured is about 750 mm / year, distributed in 77 rainy days. The distribution of rainfall shows a greater frequency in the autumn-winter period, falling to practically disappear during the summer. The rainfall regime is the "IAPE" (Winter - Autumn - Spring - Summer), which is also the most widespread in the remaining part of the island.

7.2.2 Physical-Environmental features

Geology

The area covered by this study, including data sheets, 216-217 (Cape S. Marco-Oristano) of the Geological Map of Italy produced by IGM at 1:100,000 scale, is part of the physical region of south-western Sardinia that corresponds to the fertile plains of the Campidano. This plain is displaced transversely with NW-SE direction and extends for a hundred miles from the Gulf of Oristano to the Gulf of Cagliari. The study area is located in the western part of Sardinia in the so-called Western Campidano. This is set on a Tertiary rift valley sandwiched between two Plio-Pleistocene fault scarps and then filled with alluvial material transported by Tirso River and its tributaries to the north by the rivers originating from the Monte Arci in the east, and the Rio Mogoro and Flumini Mannu. The area is made up almost entirely of Quaternary deposits, with the exception of the Sinis Peninsula and Capo Frasca, and the area adjacent to the Monte Arci volcanic complex. The main features are represented by the regional fault systems, which along the eastern edge, mark the direct tectonic line NS passing through the Monte Arci, and along the south-western edge, mark the tectonic line of Monte Arcuentu with orientation NW SSE, separating the plains from the Oligocene volcanic mountains. The description of geological formations of the geological map (Figure 7.1) is presented in Table 7.1.

Figure 7.1 Geology of the Western Campidano. (Source: IGM at 1:100,000 scale)

Code	Description
s	Current and recent sands of the beaches, coastal dunes
a	Alluvial soils or sandy stony type or clays and silty clay deposits brackish marsh
qd	more or less cemented dune sands
qd^1	Alluvial deposits sandy stony type, mostly covered with the remains of ancient dunes
q^2	Stony alluvial deposits, with interbedded sand, terraced
q^1	Stony alluvial deposits of higher terraces

Table 7.2 Legend of the IGM map.

Geomorphology

The area of the Gulf of Oristano, form a large elliptical arc, which major and minor axes respectively measure about 20 km and 10 km. The wide bay is bounded by basaltic cliffs of Capo San Marco in the North and of Capo Frasca in the South. The shoreline is characterized by low sandy coast in which we find the beaches of Mari Ermi, Is Arutas, Maimoni, San Giovanni, Su Siccu, Torre Grande, Sassu, Marina di Arborea, and Marceddì. The continuity of the coastal strip is interrupted by the presence of several river mouths, largely channelled, the Tirso River, the Rio

Mogoro and the Rio Flumini Mannu, which is interspersed with numerous lagoon channels through which the marine waters of the Gulf are connected with the wetlands of Mistras, Cabras, Santa Giusta, S'Ena Arrubia, Corru Mannu, Corru S'Ittiri, San Giovanni-Marceddì and other smaller systems. In addition to these natural wetlands, there are those transformed by historical reclamation and hydraulic works, and other small ponds that are part of major wetlands. Finally, the Sinis wetlands, complete the transition system of the area, with the pond Sa Salina, of Is Benas, of Sal'e Porcus and the wider wetland area of Cabras and Mistras, which heads the surface water drainage basin of the Rio Mare and Foghe. In the Gulf of Oristano, despite the profound changes made by man since the beginning of the last century, exist the most extensive and best-preserved wetlands in Sardinia. The sea and rivers dynamics determine, within the wetlands, the formation of water circulation channels, which provide a significant water exchange. The the water salinity varies greatly from area to area: it is fresh in the areas closest to the river interference while progressively increases in salinity in the peripheral areas.

The bathymetry of the Gulf has a maximum depth of about 20 meters, marked in the middle part of the paleo-bed of the Tirso river. The content of biogenic carbonates, originates from biomass present in Posidonia sea grass, widely extended at least up to a depth of 20 meters, which is essential for its contribution to the sedimentary budget of beaches.

Hydrography

In the Gulf of Oristano there are some of the most important waterways in Sardinia: the Tirso, the Rio Mogoro and the Rio Flumini Mannu. The Tirso basin, with an area of approximately 3,287 km2, originates near Buddusò and also crosses the provinces of Nuoro and Sassari. The basin of the Rio Mogoro with an area of approximately 399 km^2 flows into the pond of Marceddì. The catchment area of Rio Mare and Foghe and lagoon systems of Sinis, with an area of about 532 km2. The water supplies of the secondary channels from the western slopes of Monte Arci, flow into the Canal of High Water, which, in the current situation, is a tributary of the Rio Mogoro.

7.2.3 Ecological

The main values are identified by the complex and diverse ecosystem components that mark the environmental structure of the Gulf of Oristano, which are also recognized by the implementation of international conventions and national and regional legislation. Among these we mention:

- Marine Protected Area of the "Peninsula of Sinis-Isola Mal di Ventre;

- SPAs and SCIs proposed for the main coastal wetlands, headlands and islands;
- Oasis of the Wildlife Protection.

More potential of the area is represented by the use of productive environmental resources, through the activities of fishing and fish farming, which most affect areas of high natural value.

In the Gulf of Oristano, the upper limit of Posidonia oceanica, for most of its extent, it is very close to the shoreline (about 50 meters). The lower limit comes down to a depth of 10-15 meters.

Lagoon	Surface Km^2	Mean Depth	Max. Depth	Volume Mm^3	Freshwater Inflow	Habitat Type
Cabras	22.3	1.7	3	33.4	Yes	Brackish-Marine
Mistras	4.7	0.5	1	4	No	Marine-Hyperhaline
Santa Giusta	8.4	1.5	1.9	12.6	Yes	Brackish-Marine
S'Ena Arrubia	1.2	0.4	0.8	0.5	Yes	Brackish
Corru de S'Ittiri	1.5	0.8	3	4.5	No	Marine
Marceddì - San Giovanni	8.0	1	2	8	Yes	Brackish

Table 7.3 Main features of the lagoons connected to the Gulf of Oristano. (Source:Magni et al., 2008)

7.2.4 Socio-economical

People

The study area includes four municipalities: Arborea, Santa Giusta, Oristano and Cabras. The Cliff of Capo Frasca is included in the administrative area of Arbus, but being a military zone we will not consider its contribution in terms of population. The recent 2011 Census (Istat, 2013), recorded a resident population for the four municipalities of almost 50 thousand units, representing approximately 4% of the total regional municipalities (Table 7.4).

Municipality	Resident population (2001)	Resident population (2011)	Growth Rate
Arborea	3.927	4.048	0,31%
Santa Giusta	4.408	4.811	0,91%
Oristano	31.169	31.155	0,00%
Cabras	8.804	9.032	0,26%
Total	48.308	49.042	0.15%

Table 7.4 Resident population.

Oristano represents the most important city of the Province of Oristano showing a 0% growth between 2001 and 2011 (ISTAT, 2013). Oristano, Arborea, Santa Giusta and Cabras affect to a decisive extent on the socio-economic profile of the whole Province of Oristano (Costa et *al.*, 2010). The demographic profile is the result of a gradual process of coastal urbanization, littoralization, in a context of demographic aging (ISTAT, 2013).

Human capital

The area of the Gulf of Oristano, is characterized by a ratio of graduates lower than the regional level (Costa et *al.*, 2010). An indicator used to describe the level of education in the Province of Oristano is the distribution of the population over six years by educational attainment (Lattanzio & Associates, 2007). In Figure 7.2, we can see how the town of Oristano present the best performance in terms of attainment of advanced degrees (about 40% with diploma and / or degree).

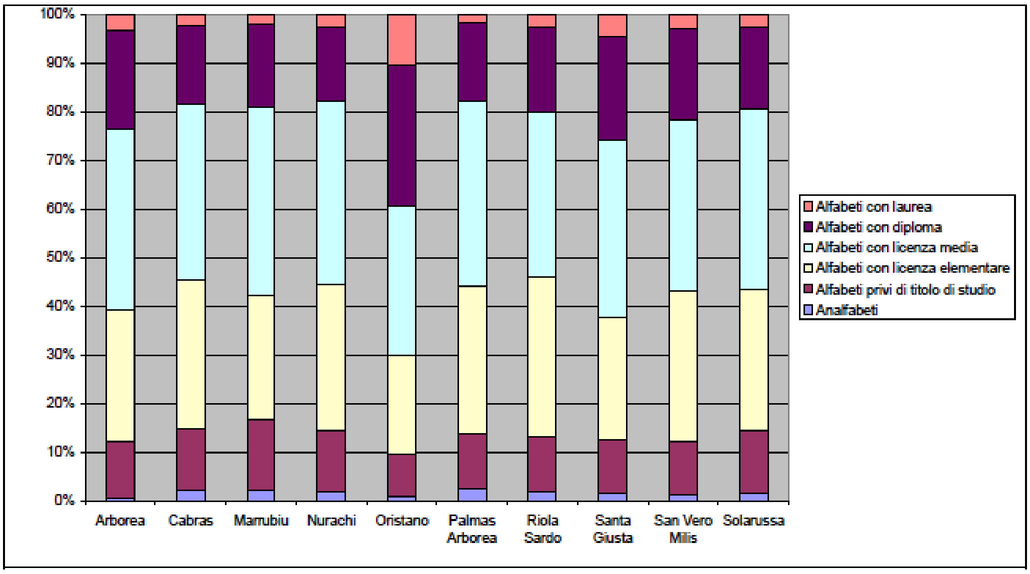

Figure 7.2 Distribution of population by educational qualifications. (Source: Lattanzio & Associati, 2007)

With regard to employment by sectors of economic activity, Table 7.5 shows that the Province of Oristano has a percentage of total employment lower than the regional average of employees in the all sectors (40,000 units) and an higher component in the agricultural sector, amounting to about 7,000 units (12% of total employment, compared with a percentage less than 7% of the regional average). So the agricultural sector, when compared to the figure of Sardinia and the other provinces, plays an important role in the productive sector of the province.

	Forze di lavoro			**Occupati per settore**			
	Totale	**- di cui Occupati**	**- di cui Persone in cerca di occupazione**	**Agricoltura**	**Industria in senso stretto**	**Costruzioni**	**Servizi**
Sassari	142,9	120,1	22,8	3,7	8,8	11,4	96,2
Nuoro	64,4	57,1	7,3	7,8	9,7	4,9	34,8
Cagliari	246,1	207,9	38,2	3,9	14,9	12,7	176,4
Oristano	**67,1**	**55,4**	**11,7**	**6,9**	**2,9**	**5,0**	**40,6**
Olbia-Tempio	74,4	64,5	9,9	3,7	5,3	5,5	49,9
Ogliastra	23,9	18,6	5,4	1,1	1,9	1,5	14,0
Medio Campidano	38,9	32,5	6,4	3,8	2,3	3,7	22,6
Carbonia-Iglesias	47,1	39,3	7,8	2,5	8,3	3,3	25,2
SARDEGNA	**704,7**	**595,3**	**109,5**	**33,4**	**54,1**	**48,0**	**459,8**
ITALIA	**25.642,4**	**22.898,7**	**2.743,6**	**849,1**	**4608,022**	**1.754,0**	**15.687,6**

Table 7.5 Labour force and employment by sectors of economic activity, absolute values (in thousands) for the Province of Oristano in 2012. (Source: Chamber of Commerce Oristano, 2013)

Urbanization

The Gulf of Oristano is characterized by the tight integration between the existing settlement structure and the environment characterized by the system of coastal wetlands. The settlement systems, located along the main river, have a form that is related morphologically to the prevailing direction of watercourses. The systems of the “Reclamations” of the fascist period (Arborea, S. Giusta, Terralba) take on the processes of land transformation as structuring conditions of the current settlement features. The structure of the coastal, presents hybrid situations (seasonal and permanent) around the main centers. In particular, the structure of the coastal, seasonal presents situations of residential areas and tourist coastal villages near the most nwell established villages (permanent): Terralba (fishing village Marceddì) Oristano (Great Tower), Arborea (Colonie Marine) Cabras (seaside towns of San Giovanni di Sinis and Funtana Meiga), San Vero Milis (S'Arena Scoada, Putzu Idu, Mandriola, Pallosu, Sa Rocca Tunda). This situation calls for a more controlled use of coastal areas for the conservation of existing natural landscapes and habitats.

Economical activities

The productive area of the Gulf of Oristano is characterized on the one hand for an important incidence of the primary sector, on the other hand, for a relative degree of industrialization, which locates around the town of Oristano the main productive activities. The following are the main economic activities of the area.

Agriculture & Livestock

The agricultural specialization of the local economy is based on two diversified models: in addition to forms of agriculture still linked to the use of traditional techniques, exists another model based on intensive productive processes. The area is characterized by the presence of productive chains related to the food industry: processing and marketing of rice Oristano; the horticultural and livestock districts of Arborea, irrigated area of Oristano and Cabras; the area suited for processing tomatoes; the wine and spirits industry. The Agricultural Census of 2,000 recorded a Total Agricultural Area (SAT) a little less than 90 thousand hectares, or approximately 5% of the regional total (Costa et al., 2010). The Utilised Agricultural Area (UAA) affects more than the regional average (almost two-thirds of the SAT), and is equal to or greater than 90% in Arborea, Cabras and Oristano (Costa et al., 2010). The herd consists of about 1,200 companies with more than 97 thousand livestock, equal to respectively 4% and 9% of the regional total. The sector is relatively specialized in the breeding of sheep and pigs, focusing on 4% of the regional total. The cattle farms account for 16% of the animals bred in Sardinia (Costa et *al.*, 2010).

Fishery

The specialization in the fishing sector has developed mainly as a result of the presence of complex lagoon of considerable size and abundance of fish, particularly in the area of Sinis. In 2005 vessels registered in the Marine District of Oristano amounted to 114 units, representing approximately 16% of the fleet in terms of regional artisanal fishing units and 15% of the total tonnage (Costa et *al.*, 2010). The "small-scale", represents the backbone of the local fleet and carries out its work seasonally in and out of the Gulf through the use of bottom trawls, gillnets, traps and longlines (Costa et *al.*, 2010). Occasionally illegally trawling is practised in the Gulf of Oristano, with negative impacts for the Posidonia sea grass.

Near the northern coast of the Gulf of Oristano, there are three systems of intensive fish farming. In the Gulf, are also located two long-line mussel farms: one, about one nautical mile long, extends in front of the Mistras Lagoon; the other is disposed between the Pesaria Channel and the north-east breakwater of the Industrial Port of Oristano. The wetlands of Oristano, are interested by intense fishing activities. The predominantly artisanal and low average tonnage of the fleet has contributed positively to the development of recreational fishing and related tourism initiatives.

Industrial and commercial activities

In 2007, the area recorded a total of approximately 1,700 active companies, representing approximately 5% of the total area within the region. In greater proportion than the regional average, the units are mostly concentrated in the manufacturing sector, with a share of 44% (41% for Sardinia). On a local scale the latter are mainly concentrated in the town of Oristano (42% of the total) (Costa et *al.*, 2010). There is consistency in the food industry, which are distinguished mainly by the activities of preservation and processing of fruit and vegetables, cereals, animal feed production, dairy industry, production of oil, wines and spirits and other groceries.

The development of the food industry, such as agriculture, has taken different forms, both artisanal and industrial, and sees currently live small business dedicated to local products and often deficient in terms of marketing strategies, in addition to industrial companies that represent successful business cases. It should be noted, finally, the widespread nature of craft production units, among others effectively represented by expressions of arts and crafts (pottery, basketry, weaving, cutlery).

Tourism

The official surveys for the year 2007 describe a range of 246 facilities with a capacity of just under 10,000 beds, which corresponds to 9% to 5% of the regional total and 6% of total beds located in coastal municipalities of the Region. The hotel accommodation accounts for less than a third of capacity (compared to a regional average of more than 50%), with a relatively greater weight of lower-middle range units (Costa et *al.*, 2010). T

he sizing of the non-hotel sector depends on the consistency of the outdoor facilities, amounting to more than 80% of capacity and complementary with a number of beds doubled compared to the hotel (Costa et *al.*, 2010). In analogy with the entire region, the phenomenon of secondary homes for tourism is an important aspect to consider.

Recent surveys report an estimate of the beds associated with units not occupied by residents and at the same time were used as a holiday in excess of 55 thousand units. In terms of infrastructural facilities the area detects the presence of a marina, with a total capacity of about 750 boats. The marina of Torre Grande, in the town of Oristano, currently has 400 berths.

The analysis of tourist flows reflects the main structural features described on the supply side. The data for 2013 reveal over 143 thousand arrivals and 436 thousand visitors[23].

Mobility and trasports

The town of Oristano is identified as the primary center of gravity, where a large part of public transport, is conditional on the fulfilment of basic needs related to school and work commuting, and seasonal flows to the coastal areas. This is especially true in the summer, when there is the presence of a strong tourist movement concentrated in coastal areas. Among the major infrastructure nodes in the area, the airport of Oristano-Fenosu is currently configured as a "civil airport opened to traffic General Aviation", therefore excludes, at the time, the commercial traffic (passengers and freight).

They are an on-going series of infrastructure geared to enhance their capabilities in view of the recognition by ENAC status of commercial airport. The Port of Oristano is the only regional port "dedicated" to bulk goods operations and services. Classified since 2002 as a port of national economic importance, the harbour is located at the industrial consortium, between the towns of Oristano and S. Giusta.

An analysis of the flow of goods between 2001 and 2007 there has been a steady annual decline, estimated globally at around 20% (Costa et *al.*, 2010).

Cultural heritage

The historic coastal settlements in the Gulf of Oristano (e.g. Othoca, Tharros and Neapolis) accounted for since the fourth millennium BC a bridge of trade. Along the routes to and from Sardinia have come and gone peoples and cultures: the Phoenicians, Carthaginians, Romans, Vandals, Pisans and Genoese, Catalan-Aragonese, Piemontese, with which local people have interacted.

The landscape forms, the evidence of archaeology, architecture scattered along the coasts are a sign of this meeting, exchange and processing techniques, iconography, traditions, religions. The whole coast of the Gulf of Oristano is characterized by the presence of coastal towers of Aragonese origin.

A Regional Town Plan (RTP) was created in 2004 in Sardinia to protect the landscape and the environment of Sardinia as a "*modern legislative framework which guides and coordinates*

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[23] Provincia di Oristano – http://www.provincia.or.it (accessed July 26, 2014)

planning and sustainable development of the island starting with the coasts" (Garau & Pavan, 2010).

The RTP aims to protect the cultural heritage and the cultural landscape "*conserving the historic and characteristic elements, highlighting their value and promoting improvements through restoration, reconstruction, reorganisation and restructuring even where the landscape is degraded or jeopardised*" (Garau & Pavan, 2010).

7.3 The coastal units defined for the study area

Particularly relevant for the application of the coastal risk assessment method, is the identification of the coastal spatial unit for the study area. Beach shores, cliff shores and lagoons represent the coastal units defined for this research. In Table 7.5 we list the 21 coastal physiographical units in which the study area of the Gulf of Oristano has been divided.

n.	Coastal unit	Type of Shore
1	Mari Ermi Nord	Beach
2	Mari Ermi Centro	Beach
3	Mari Ermi Sud	Beach
4	Is Arutas	Beach
5	M.te Corrigas	Beach
6	Maimoni Nord	Beach
7	Maimoni Centro	Beach
8	Maimoni Sud	Beach
9	Is Coagheddas	Beach
10	Promontorio di Seu	Cliff
11	Funtana Meiga	Beach

n.	Coastal unit	Type of Shore
11	Funtana Meiga	Beach
12	San Giovanni	Beach
13	Istmo Capo San Marco	Beach
14	Capo San Marco	Cliff
15	Su Siccu	Beach
16	Marina di Torregrande	Beach
17	Sassu	Beach
18	Marina di Arborea	Beach
19	Corru S'Ittiri	Lagoon
20	Spiaggia di Marceddi	Beach
21	Capo Frasca	Cliff

Table 7.6 Coastal units

The study area includes the Gulf of Oristano and the Sinis coastal zones with the limit of Mari Ermi beach in the North and Capo Frasca Cliff in the south (Fig. 7.3).

Figure 7.3 The Oristano Lagoon - Gulf system. (Source: Magni et *al*. 2008)

A very high density of salt marshes and lagoons characterizes the Gulf of Oristano. These ecosystems are shallow eutrophic water bodies (approximately 0.5-2 m depth). Several of these lagoons are part of the Ramsar Convention on Wetlands and the Natura 2000 network. However, Oristano lagoons have recently experienced high anthropogenic pressure due to massive nutrient loading, reduction of freshwater input from upland, modifications of the inlets and other man-made interventions, which have reduced the water exchange with the Gulf of Oristano (Magni et *al.*, 2008). Another relevant aspect is the presence of the Marine Protected Area of Sinis-Mal di Ventre.

7.4 Summary

The coastal system of the Gulf of Oristano is chosen as a study area for the application of the coastal risk assessment method defined for this research.

The Gulf of Oristano is mainly characterised by low-lying areas particularly vulnerable to sea level rise and coastal flooding.

Main climate forcing acting on the Gulf of Oristano is represented by Storms. Non-climate drivers play a less relevant role. Population growth rate is stable or even decreasing. Tourism is not relevant compared with the rest of Sardinia but has a great potential of growth in the future.

Saltwater intrusion represents the main hazard in the area and it already affects the coastal aquifer of Arborea. Saltwater intrusion represents a very relevant risk for agriculture as the most important economic activity of the area.

The study area is divided in 21 coastal units according to coastal geomorphology: 17 beach shores, 3 cliffs and 1 lagoon.

CHAPTER 8. RISK ASSESSMENT OF THE COASTAL EROSION HAZARD ZONE

8.1 Introduction

In the context of the Gulf of Oristano, the tendency to erosion it is significant in the beaches of Is Arutas, Funtana Meiga and San Giovanni (Costa et *al.*, 2010). Sandy coastal systems in erosion are generally accompanied by enhanced degradation of dune systems. The coastal areas of the Gulf of Oristano are affected by poor adaptation to changes in the dynamic marine processes affecting the coastal physiographical units, generating irreversible processes of shoreline and high cliffs retreat. The main effects of erosion on the coast of the Gulf of Oristano, resulting in damage to road infrastructure, damage to coastal settlements, economic damage to the seaside tourism industry (Costa et *al*., 2010). Regarding erosion on coastal ecosystems, the following impacts have been observed: psammophilous subtraction of habitat, fragmentation of dunes, sedimentary deficit and subtraction of natural and environmental resources value (Costa et *al*., 2010). About the cliff shore of the Gulf of Oristano, we have frequent phenomena of gravitational collapse and fall of rock masses along the coastal slopes and cliffs. These are usually in geomorphological conditions of instability related to the evolution of the shoreline forced by marine dynamics.

In general, the areas characterized by phenomena of coastal “stiffening” and artificialisation have shown (Costa et *al.*, 2010):

- A low adaptive capacity of the coast to the variability of coastal dynamics during ordinary and extreme events;
- Alteration of the energy regime and sediment physiographic unit belongs; induction of localized erosion;
- Alteration of the relationship dynamics and fluvial-marine lagoon (e.g. Marina di Arborea).

To assess the coastal erosion risk of the Gulf of Oristano shoreline, we apply the Coastal Erosion Risk Index (CERI). We initially proceed to the identification of the coastal erosion hazard zones and then to the definition of variables for the factors, which characterize the risk function.

RISK*ero* = f (FOR*ero*, HAZ*ero*, VULN*ero*, EXP*ero*).

Where the component “VULN*ero”* is described by “SUSC*ero”* and “RES*ero”.*

The physical-environmental variables of Susceptibility, Resilience and Exposure, are computed for each coastal unit as defined in Section 7.3. The socioeconomic variables are instead associated to the administrative unit of reference, in most instances the municipalities, to which the coastal units belong. The unit of reference for the assessment of land use based on CORINE LCL cells were built on 100m x 100m. Through the use of ARCGIS, we make a downscaling of 10m x 10m cells to approximate as much as possible the coastline and associated information also at very small shorelines.

8.2 The Coastal Erosion Hazard Zone

For the identification of the Coastal Erosion Hazard Zone (CEHZ) we adopt the revisited formulas of Tonkin & Taylor (2004), already presented in Section 6.4.3, for beach shores and cliffs shores.

We consider the coastal units defined in Table 7.6 of Section 7.3.

The lagoon of Corru S’ittiri is separated from the sea by a beach strip. For this reason, we also consider Corru S’ittiri as a beach for the definition of the Hazard Zone.

8.2.1 Hazard zone for beach shores

The width of the hazard zone width for beach shores is given by the following formula proposed by Tonkin & Taylor (2004).

Hz = ST + SE + DS + SL + LT

Horizontal short-term fluctuations (ST)

It’s equal to two times the standard deviation of annual shoreline movement at each profile measured 1.0 m above the MSL. The short-term fluctuation takes account of the variability of the long term trend of shoreline movements. This aspect is particularly important for coasts close to being in a state of dynamic equilibrium. For these beaches while the long term trend is one of stability with little net change there are fluctuations in shoreline position with the shoreline retreating at times and accreting at other times. There are several methods that could be used to measure short-term fluctuations in beach positions. One empirical method is the maximum-recorded retreat. According to a study of Simeone et al. (2006) the records on short-term fluctuation, measured for some beaches in different period of the year, can be approximated to 1 m/y for the 18 beaches of the Gulf of Oristano. In the case of lack of beach shoreline historical observations the software DSAS for ARCGIS can be used. Through the analysis of historical photos, DSAS allows to measure the short-term and long-term fluctuations considering images taken in different periods of the year (possibly winter and summer). DSAS is a software extension to ESRI ArcGIS v.10 that enables a user to calculate shoreline rate-of-change statistics from multiple historical shoreline positions (Thieler et *al*., 2009).

Shoreline response to storm erosion SE

Equal to the standard deviation of annual shoreline movement at each profile measured 1.0 m above the MSL. The MPA "Sinis Mal di Ventre" periodically monitors the beaches of the Gulf of Oristano and of the Sinis Peninsula. Thanks to the expert of the MPAS's, it has been possible to determine the maximum shoreline change related to some extreme storm events. We apply a factor of 1,25 to these distances to estimate a storm cut likely to be great than a cut with a return period of between 50 and 100 years (Tonkin & Taylor LTD, 2004). The final values of SE for the 17 beaches and the lagoon of Corru S'Ittiri are indicated in Table 8.1.

n.	Beach	SE (m)
1	Mari Ermi Nord	15
2	Mari Ermi Centro	15
3	Mari Ermi Sud	15
4	Is Arutas	18,75
5	M.te Corrigas	15
6	Maimoni Nord	15
7	Maimoni Centro	15
8	Maimoni Sud	15
9	Is Coagheddas	6,25
10	Funtana Meiga	13,75
11	San Giovanni	13,75
12	Istmo Capo San Marco	13,75
13	Su Siccu	6,25
14	Marina di Torregrande	10
15	Sassu	16,25
16	Marina di Arborea	11,5
17	Corru S'Ittiri	15
18	Spiaggia di Marceddi	11,25

Table 8.1 Shoreline response to storm erosion (SE).

Distance from above 1.0 m above MSL to the active dune/beach (DS)

The width of the existing beaches is assumed to remain constant in width even with ongoing shoreline retreat. The mean distance is measured in ARCGIS v.10 and reported in Table 8.2.

n.	Beach	DS (m)
1	Mari Ermi Nord	85
2	Mari Ermi Centro	85
3	Mari Ermi Sud	85
4	Is Arutas	90
5	M.te Corrigas	160
6	Maimoni Nord	160
7	Maimoni Centro	160
8	Maimoni Sud	160
9	Is Coagheddas	95
10	Funtana Meiga	90
11	San Giovanni	90
12	Istmo Capo San Marco	90
13	Su Siccu	180
14	Marina di Torregrande	170
15	Sassu	210
16	Marina di Arborea	390
17	Corru S'Ittiri	30
18	Spiaggia di Marceddi	25

Table 8.2 Distances from the active dunes (DS)

Magnitude of shoreline retreat due to possible accelerated sea level rise (SL)

The potential shoreline retreat for a given sea level can be measured through empirical models like the modified Bruun rule approach excluding allowance for local relative sea level rise change due to tectonic activity (Tonkin & Taylor, 2004).

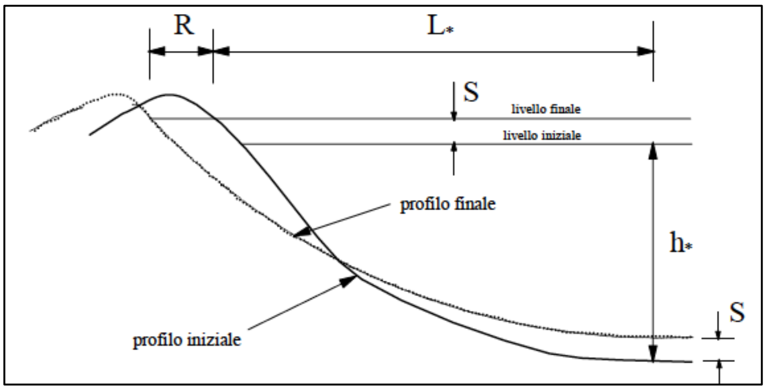

Figure 8.1 Profile of the beach shore regression due to SLR.

$$R = \frac{L_* \cdot S}{B + h_*} \quad (8.1)$$

Where L* is the horizontal distance between the coastline and the limit of the "active zone" bounded by the depth h*, and B is the height of the emerged beach. The equation 8.1 can also be written as: R = S / tan θ. Where R = SL.

Where tanθ ≈ (B + h *) / L * is the average slope of the profile of the coast in a wide band L *.

For SLR we consider the climate change scenario in 2100. In the IPCC's Fifth assessment report the likely range of sea level rise in 2100 for the highest climate change scenario is 52 to 98 centimeters (IPCC, 2014). The range up to 98 cm is the IPCC's "likely" range. In the Summary for Policy Makers (2014), IPCC states that "several tenths of a meter of sea level rise during the 21st century" could be added to this if a collapse of marine-based sectors of the Antarctic ice sheet is initiated.

We can then consider that 0,98cm is not the upper limit. In this sense, Anders Levermann lead author of the sea level chapter for the IPCC's Fifth Assessment Report propose an *upper limit of 1.5 meters for 2100*[24].

We adopt a precautionary level of SLR = 1,5 m. The slope is measured for each beach calculating the average slope measured for the submerged beach and the emerged beach profile. We used the records from the study of Simeone et al. (2006).

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[24] E360 YALE - http://e360.yale.edu/content/feature.msp?id=2698 (accessed July 28, 2014)

n.	**Coastal stretch**	**Mean slope emerged beach (%)**	**Mean slope submerged beach (%)**	**Mean slope (%)**	**θ (degrees)**	**SLR**	**Tanθ**	**SL (m)**
1	Mari Ermi Nord	9,6	6,43	8,0	7,20	1,5	0,126	**12**
2	Mari Ermi Centro	7,1	3,21	5,1	4,62	1,5	0,081	**19**
3	Mari Ermi Sud	12,1	2,03	7,1	6,35	1,5	0,111	**13**
4	Is Arutas	10,0	6,43	8,2	7,39	1,5	0,130	**12**
5	M.te Corrigas	2,9	2,88	2,9	2,59	1,5	0,045	**33**
6	Maimoni Nord	7,9	2,75	5,3	4,77	1,5	0,084	**18**
7	Maimoni Centro	5,3	3,98	4,7	4,19	1,5	0,073	**20**
8	Maimoni Sud	7,8	2,43	5,1	4,60	1,5	0,081	**19**
9	Is Coagheddas	9,1	1,36	5,2	4,71	1,5	0,082	**18**
10	Funtana Meiga	7,2	1,79	4,5	4,05	1,5	0,071	**21**
11	San Giovanni	9,1	2,16	5,6	5,04	1,5	0,088	**17**
12	Istmo Capo San Marco	5,6	1,87	3,7	3,36	1,5	0,059	**26**
13	Su Siccu	9,4	1,05	5,2	4,69	1,5	0,082	**18**
14	Marina di Torregrande	8,1	1,20	4,7	4,19	1,5	0,073	**20**
15	Sassu	7,72	2,30	5,0	4,51	1,5	0,079	**19**
16	Marina di Arborea	1,55	2,20	1,9	1,69	1,5	0,029	**51**
17	Corru S'Ittiri	1,55	2,20	1,9	1,69	1,5	0,029	**51**
18	Spiaggia di Marceddi	1,66	2,56	2,1	1,90	1,5	0,033	**45**

Table 8.3 Magnitude of shoreline retreat due to possible accelerated sea level rise (SL).

Long-term rate of horizontal shoreline movement LT (m/y)

Long-term trends for each beach profile demand data sets with records of at least 20-30 years. Shorter records are likely to include significant scatter due to the natural dynamic movement of the beach system. Shoreline change rates are calculated from the time series of historical shoreline positions using a variety of statistical methods. One simple method is proposed by Podoski (2013) and a significant review is presented by Pranzini and Wetzel (2007). The CGG research group of the University of Hawaii uses the single-transect (ST) method to calculate shoreline change rates. ST calculates a shoreline change rate and uncertainty at each transect using various methods to fit a trend line to the time series of historical shoreline positions (Romine et *al*., 2009). We also adopt weighted least squares (WLS), which accounts for the uncertainty in each shoreline position when calculating a trend line (Romine, 2013; Romine et *al*., 2009). Also for the LT calculation (1960-2000) we apply DSAS to historical photos (Thieler et *al*., 2009).

n.	Beach	LT
1	Mari Ermi Nord	-7,8
2	Mari Ermi Centro	1,7
3	Mari Ermi Sud	1,5
4	Is Arutas	-20,6
5	M.te Corrigas	3,2
6	Maimoni Nord	3,5
7	Maimoni Centro	-6,3
8	Maimoni Sud	0,8
9	Is Coagheddas	0,5
10	Funtana Meiga	-12,1
11	San Giovanni	-12,6
12	Istmo Capo San Marco	-10,2
13	Su Siccu	18,6
14	Marina di Torregrande	21
15	Sassu	-6,2
16	Marina di Arborea	1,6
17	Corru S'Ittiri	1,5
18	Spiaggia di Marceddi	2,5

Table 8.4 Long-term rate of horizontal shoreline movement.

Width of the beach shore hazard zone Hz (m)

The width of the hazard zone is the sum of the previous values expressed in meters.

n.	Beach	ST	SE	DS	SL	LT	Hz
1	Mari Ermi Nord	1	15	85	11,88	-7,8	**105**
2	Mari Ermi Centro	1	15	85	18,57	1,7	**121**
3	Mari Ermi Sud	1	15	85	13,48	1,5	**116**
4	Is Arutas	1	18,75	90	11,56	-16,6	**105**
5	M.te Corrigas	1	15	160	33,13	3,2	**212**
6	Maimoni Nord	1	15	160	17,96	3,5	**197**
7	Maimoni Centro	1	15	160	20,50	-6,3	**190**
8	Maimoni Sud	1	15	160	18,63	0,8	**195**
9	Is Coagheddas	1	6,25	95	18,22	0,5	**121**
10	Funtana Meiga	1	13,75	90	21,21	-12,1	**114**
11	San Giovanni	1	13,75	90	16,99	-12,6	**109**

12	Istmo Capo San Marco	1	13,75	90	25,54	-10,2	**120**
13	Su Siccu	1	6,25	180	18,27	18,6	**224**
14	Marina di Torregrande	1	10	170	20,50	19,7	**221**
15	Sassu	1	16,25	210	19,02	-6,2	**240**
16	Marina di Arborea	1	11,5	390	50,91	1,6	**455**
17	Corru S'Ittiri	1	15	30	51,00	1,5	**99**
18	Spiaggia di Marceddi	1	11,25	25	45,24	2,5	**85**

Table 8.5 Width of the Coastal Erosion Hazard Zone for beach shores.

8.2.2 Hazard zone for cliff shores

The width of the hazard zone for cliff shores is calculated as follow.

Hz = 2 H + (LT x T)

Where:

H = the height of the cliff above its toe. For a precautionary principle, we use the highest value

LT = the long term rate of horizontal shoreline movement (m/y) as determined by the expert opinion, based on site inspection and a comparative review of historical and recent aerial photographs

T = planning time period (100 years)

As well as for the beach shore the complete methodology to calculate Hz for cliff shores can be found in Tonkin and Taylor LTD (2004). The values measured for the three cliff shores included in the study area are reported in the Table 8.6. We consider a planning period of 100 years so T = 100.

	H (m)	LT (m/y)	T (years)	Hz
Promontorio di Seu	11	0,0375	100	**26**
Capo San Marco	36	0,03	100	**75**
Capo Frasca	85	0,25	100	**195**

Table 8.6 Width of the hazard zone for cliff shores.

8.2.3 Mapping the CEHZ

By calculating the width of the hazard zone for beach and cliff shorelines, we can trace the upper limit of the hazard zone for the whole study area. The setback line for coastal erosion hazard represents the upper limit of the Hazard zones. Distances Hz, are measured from the shoreline. The zones between different distances have been interpolated through the use of ARCGIS. When approaching the areas of connection between two coastal units, for a precautionary principle, we considered the greatest distance from the shoreline. Regarding the port areas, we establish that there is no hazard as these areas are inerodible. We draw the Coastal Erosion Hazard Zones (CEHZ) and the Erosion Setback Line with ARCGIS (Figure 8.2). The upper limit of the Coastal Erosion Hazard Zone represents the Erosion Setback line.

Figure 8.2 Coastal Erosion Hazard Zones. Northern shore (left) and Southern shore (right).

8.3 Forcing to Coastal Erosion

8.3.1 SLR

As a proxy for the current SLR observed the Gulf of Oristano we refer to satellite altimetry trends (Figure 8.3). In the western shore of Sardinia the trend of SLR ranges between 2,5 mm/y (yellow) and 3,5 mm/y (orange).

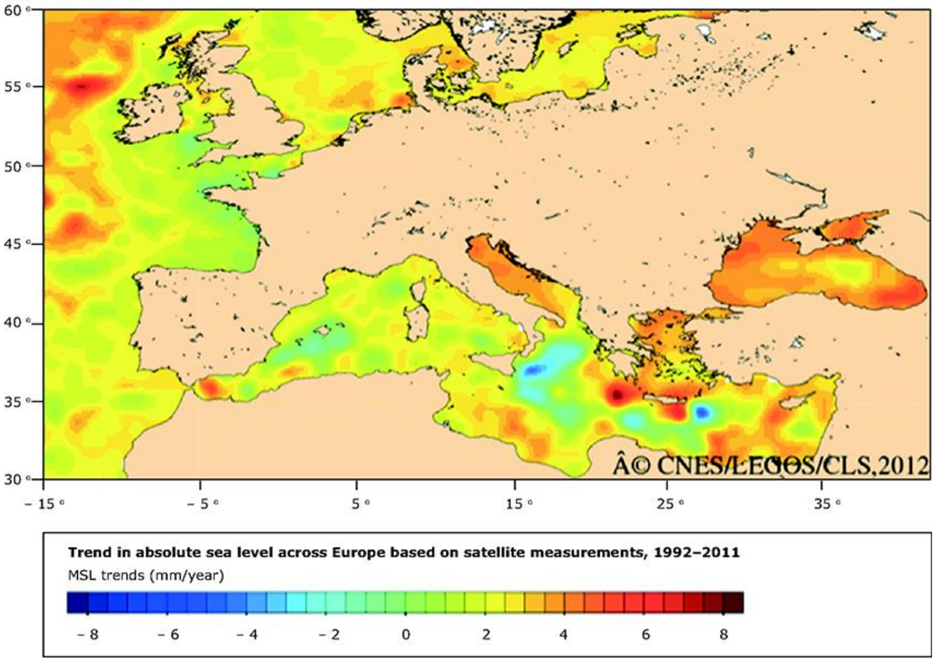

Figure 8.3 Trend in absolute sea level across Europe based on satellite measurements, 1992 – 2011 (Source: EEA, 2014).

According to the scale defined for this research (Table 8.7) these values correspond to a moderate forcing with score equal to 3.

Level of forcing	Rate (mm/y)	Score
Very High	SLR > 6	5
High	4 < SLR ≤ 6	4
Moderate	2 < SLR ≤ 4	3
Low	0 < SLR ≤ 2	2
Very Low	SLR ≤ 0	1

Table 8.7 SLR trends Forcing classes.

8.3.2 Storms

The ST variable is measured as the average number of detected SWH above 95 percentile / year (SWHX95n). As a proxy for the variable SHWx95n, we consider the projection from the study realized by Pino et al. (2009) for all the Mediterranean Sea (Figure 8.4). The analysis provided by this study covers a 44-year long period (1958-2001).

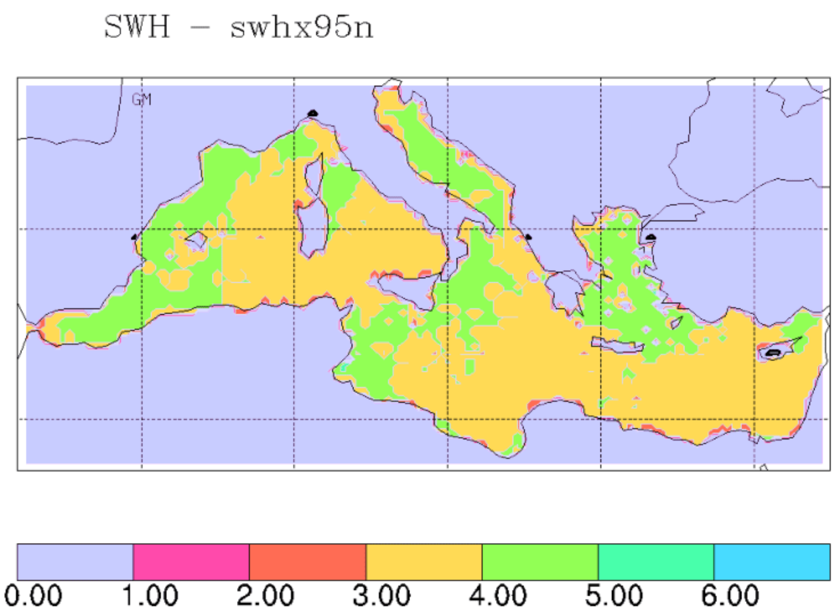

Figure 8.4 Number of detected SWH above 95 percentile. (Source: Pino et al., 2009)

The western coastal areas of Sardinia are characterized by the colour orange that corresponds to an SWHx95n between 3 and 4 events per year.

According to the classes defined for this research and reported in Table 8.8 these values correspond to a score 3 (moderate forcing).

Level of Storms forcing (SWHx95n)	Trend (n/y)	Score
Very High	> 6	5
High	4 < r ≤ 6	4
Moderate	2 < r ≤ 4	3
Low	1 < r ≤ 2	2
Very Low	r < 1	1

Table 8.8 Storms trend Forcing classes.

8.3.3 Human Development

The resident population growth rate is estimated by elaborating national statistics data (ISTAT, 2013) based on the comparison between the Census 2001 and the Census 2011.

Municipality	Resident population (2001)	Resident population (2011)	Growth Rate
Arborea	3.927	4.048	0,31%
Santa Giusta	4.408	4.811	0,91%
Oristano	31.169	31.155	0,00%
Cabras	8.804	9.032	0,26%
Total	48.308	49.042	0.15%

Table 8.9 Population of the municipality included in the study area for Census 2001 and 2011. (Source: Istat, 2013)

The growth rate is positive for Arborea, Santa Giusta and Cabras and negative for Oristano but almost stable. We decide to assume an average growth rate of the area equal to 0,15% per year. According to the scale defined for this research (Table 8.10) this value corresponds to a score 2 (low forcing).

Level of forcing	Population Average Rate Growth	Score
Very High forcing	ARG > 2%	5
High forcing	1% < ARG < 2%	4
Moderate forcing	0,5% < ARG < 1%	3
Low forcing	0,1 % < ARG < 0,5%	2
Very Low forcing	ARG < 0,1 %	1

Table 8.10 Ranking for Human Development forcing.

8.3.4 Tourism development

The TD factor is a measure through the arrivals in a defined period. For the area of the Gulf of Oristano, we consider the dataset of the regional statistics observatory[25] available at the scale of the Province of Oristano for the 2007 – 2011 period.

	Arrivals, Hotels	Arrivals, Extra-Hotels	Arrivals, Total
2007	86.212	31.919	118.131
2008	86.039	31.759	117.798
2009	92.017	33.127	125.144
2010	97.680	34.709	132.389
2011	96.636	35.626	132.262

Table 8.11 Arrivals in the Province of Oristano. (Source: Sardegna Statistiche, 2014)

The annual growth rate in equal to 2,4% that in the scale defined for this research (Table 8.12) corresponds to a score 3 (moderate forcing).

Level of forcing	Tourism arrivals Average Rate Growth	Score
Very High forcing	ARG > 10%	5
High forcing	5% ≤ ARG < 10%	4
Moderate forcing	1% ≤ ARG < 5%	3
Low forcing	0 % ≤ ARG < 1%	2
Very Low forcing	ARG < 0 %	1

Table 8.12 Ranking for Tourism Development forcing.

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[25] SardegnaStatistiche - http://www.sardegnastatistiche.it/argomenti/turismo/ (accessed July 29, 2014)

8.3.5 Forcing factor calculation

Let’s resume the scores assigned to each variable of the Forcing factor.

Variable	Score
SLR	3
ST	3
HD	2
TD	3

Table 8.13 Scores of forcing variables for Erosion.

Now we need to assign a weight to each variable. We decide weights in an empirical way. The SLR component is relatively important as a driver for coastal erosion in the study area. We choose to assign a value of 25%.

The Storms component is the most relevant in terms of Forcing for the coastal erosion. In fact, the shoreline of the Gulf of Oristano is highly exposed to strong mistral winds. For this reason, we choose to assign a weight of 40%.

Concerning the non-climate forcing, we decide to assign a relative lower weight to the parameter HD. In fact, considering the aging of the population and the low-density housing (Costa et *al*., 2010) we can assume a modest contribution (15%) of this factor in the future development perspective.

On the other side, the TD component can be considered a relevant non-climate driver in the view of potential future development. The coastal area of the Gulf of Oristano, compared to other coastal areas of Sardinia, is relatively less developed in terms of tourism. Nevertheless current tourism projects (e.g. IVI Petrols investment in Torre Grande) and an active interest from Italian and foreign investors (e.g. Qatar Holding), warns a significant coastal tourism development in the next decades. We choose a weight of 20%.

Weights	Value
Wslr	35%
Wst	35%
Whd	10%
Wtd	20%

Table 8.14 Weights of forcing variables.

The Forcing factor for erosion hazard, FOR*ero*, is the sum of the weighted forcing components (SLR, ST, HD and TD) divided per 5 and multiplied per 4 as showed in the following equation.

$$FORero = \frac{SLR*wslr+ST*wst+HD*whd+TD*wtd}{5} * 4 = \mathbf{2,32}$$

The score 2,32, according to the classes of forcing defined in Table 6.10 of Section 6.5.3, represents a moderate forcing.

8.4 Erosion Hazard

The variable chosen to describe the Coastal Erosion Hazard is the historical Shoreline Change (SC) that describes the rate of change of shoreline position per year for a specific time spam.

Historical shoreline positions are derived from 1954 and 2008 aerial photographs. Photos depict the shoreline at a single instant but represent the shoreline location for a decade or more in a historical shoreline data set. The historical shoreline rate is calculated by Digital Shoreline Analysis System (DSAS) version 4.3.

These rates are referred to beach shores. Even if cliff shores are not dynamic like beaches and most of all they can be stable or in erosion, we decide to apply the same rates. Considering the whole coastline of the Gulf of Oristano from Capo Frasca to the Mari Ermi beach we have 17 beach shores, one lagoon beach (Corru S'Ittiri) and three cliff shores.

The results are also compared with the historical shoreline rates defined in the report of Simeone et al. (2006). The report presents data from 1960 to 2000 for 13 beach shores except Marina di Torregrande, Sassu, Marina di Arborea e Marceddi.

Considering that these values range from -0,533 (erosion) for Maimoni beach to 0,525 (accretion) for Torregrande beach, we decide to adjust the categories proposed by Benassai et al. (2012). The aim is to highlight the variability in terms of erosion and accretion. The Erosion Hazard and the indicator chosen for its definition are highly dependent from local conditions. We suggest adapting the Hazard variability levels to the existing scientific literature on historical shorelines changes at the local or at least at the national level. It would be useful to define the classes based on a macro physiographical unit (e.g. the whole Sardinian western coast). Decreasing the level of classes' variability, we can finally appreciate the positive effect of the phenomenon of beaches accretion that counteracts the Forcing factor. We report here the table presented in Section 6.6.1 (Table 8.15).

Level or erosion impact	Rate of erosion/accretion (m/y)	Score
High erosion	r > - 1.0	4
Moderate erosion	- 0,5 ≤ r < - 1.0	3
Low erosion	- 0.1 ≤ r < - 0,5	2
Stability	0,1 ≤ r < - 0.1	1
Low Accretion	0,1 ≤ r < 0,5	1/2
Moderate Accretion	0,5 ≤ r < 1	1/3
High Accretion	> 1.0	1/4

Table 8.15 Proposed classification for the Erosion hazard factor.

Scores assigned to each coastal unit are reported in the last column of Table 8.16. The Erosion hazard (HAZ*ero*) variability along the coast depends by many different factors.

	Coastal unit	Type of Shore	Shoreline Change (m)	Rate of erosion accretion (m/y)	HAZ_{ERO}
1	Mari Ermi Nord	Beach	-7,8	-0,195	**0,5**
2	Mari Ermi Centro	Beach	1,7	0,043	**1**
3	Mari Ermi Sud	Beach	1,5	0,038	**1**
4	Is Arutas	Beach	-20,6	-0,515	**3**
5	M.te Corrigas	Beach	3,2	0,080	**1**
6	Maimoni Nord	Beach	3,5	0,088	**1**
7	Maimoni Centro	Beach	-6,3	-0,158	**2**
8	Maimoni Sud	Beach	0,8	0,020	**1**
9	Is Coagheddas	Beach	0,5	0,013	**1**
10	Promontorio di Seu	Cliff	1,5	0,038	**1**
11	Funtana Meiga	Beach	-12,1	-0,303	**0,5**
12	San Giovanni	Beach	-12,6	-0,315	**0,5**
13	Istmo Capo San Marco	Beach	-10,2	-0,255	**0,5**
14	Capo San Marco	Cliff	1,2	0,030	**1**
15	Su Siccu	Beach	18,6	0,465	**2**
16	Marina di Torregrande	Beach	21	0,525	**3**
17	Sassu	Beach	-6,2	-0,155	**0,5**
18	Marina di Arborea	Beach	1,6	0,040	**1**
19	Corru S’Ittiri	Lagoon	1,5	0,038	**1**
20	Spiaggia di Marceddi	Beach	14,2	0,355	**1**
21	Capo Frasca	Cliff	0	0,000	**1**

Table 8.16 Shoreline changes of beach and cliff shores of the Gulf of Oristano.

Except the beach of Marina di Torregrande, Is Arutas and Maimoni, scoring low erosion, the other shorelines present a steady state if we consider a historical shoreline changes on 54 years time span.

8.5 Vulnerability to Erosion

8.5.1 Susceptibility to Erosion

Variables chosen to describe Susceptibility to Coastal Erosion are Landform, Artificial Frontage, Coastal slope, Sediment budget, River Flow Regulation. The scores for the Susceptibility variables are calculated and assigned to every cell of the GRID defined for the Coastal Erosion Hazard Zone.

The variables are presented below in detail, and the corresponding classes of susceptibility are reported in Table B.1 of Appendix B.

Landform

This variable is calculated through Geological Map (1: 25.000) of the Regione Sardegna. Values are reported in the GIS database.

Artificial Frontage

For artificial frontage, we mean marittime features that in some cases have be constructed to protect the coast, but in other cases have a negative impact in terms of erosion. Artifical frontage is characterised by ports, harbours, groynes, detached breakwaters, artificial headlands, etc.. These interventions have an impact on natural ecosystems emerged and submerged and sometimes on the balance sedimentological and hydrodynamic coastal. The tightening of the coastal stretches prevents the coastline to evolve naturally according to the weather and sea conditions, often causing erosion and sedimentation within physiographic. The Artificial Frontage variable is calculated as the total value of land use for the first line of each sub-cell 10m x 10m included in a cell 100m x 100m (or 250m x 250m). It is assumed that the first line of cells of side 10 is a good proxy of water frontage. Following is calculated by the percentage of cells 10m x 10m artificially modelled with respect to the line of length 100 (10 cells) or 250 (25 cells).

Coastal slope

For the slope of beaches shoreline, we adopt the values of the emerged beach measured by Simeone et al. (2006). The value for cliffs slope is calculated through the "slope" function of ARCGIS 10 for all the cells included in the CEHZ (Table 8.17).

Coastal stretch	Type of Shore	Mean Slope (%)	Score
Mari Ermi Nord	Beach	9,6	2
Mari Ermi Centro	Beach	7,1	2
Mari Ermi Sud	Beach	12,1	1
Is Arutas	Beach	10,0	1
M.te Corrigas	Beach	2,9	4
Maimoni Nord	Beach	7,9	2
Maimoni Centro	Beach	5,3	2
Maimoni Sud	Beach	7,8	2
Is Coagheddas	Beach	9,1	2
Promontorio di Seu	Cliff	24	1
Funtana Meiga	Beach	7,2	2
San Giovanni	Beach	9,1	2
Istmo Capo San Marco	Beach	5,6	2
Capo San Marco	Cliff	36	1
Su Siccu	Beach	9,4	2
Marina di Torregrande	Beach	8,1	2
Sassu	Beach	7,72	2
Marina di Arborea	Beach	1,55	5
Corru S'Ittiri	Lagoon	1,55	5
Spiaggia di Marceddi	Beach	1,66	5
Capo Frasca	Cliff	29	1

Table 8.17 Beach and Cliff shorelines Slope.

Historical Sediment Budget

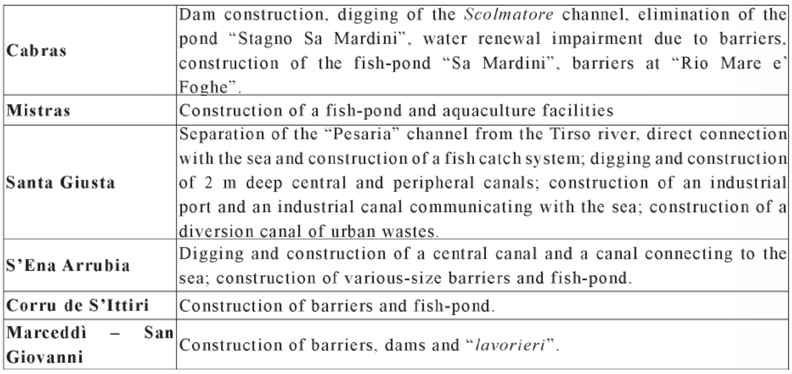
This value was calculated by the mean of ARCGIS as a difference between the extensions of the beach in 1954 compared with the extension in 2008 through the in-depth analysis of the georeferenced aerial images (Table 8.18).

	Beach	Sediment budget	Score
1	Mari Ermi Nord	-28%	4
2	Mari Ermi Centro	-4%	3
3	Mari Ermi Sud	-8%	3
4	Is Arutas	-31%	5
5	M.te Corrigas	-35%	5
6	Maimoni Nord	-23%	4
7	Maimoni Centro	-39%	5
8	Maimoni Sud	-26%	4
9	Is Coagheddas	-6%	3
10	Promontorio di Seu		1
11	Funtana Meiga	-6%	3
12	San Giovanni	13%	2
13	Istmo Capo San Marco	39%	1
14	Capo San Marco		1
15	Su Siccu	6%	3
16	Marina di Torregrande	19%	2
17	Sassu	-13%	4
18	Marina di Arborea	15%	2
19	Corru S'Ittiri	15%	2
20	Spiaggia di Marceddi	-28%	4
21	Capo Frasca		1

Table 8.18 Beaches Sediment Budget.

River flow regulation

In the area of the Gulf Oristano, there are several infrastructures to regulate river flows (e.g. Tirso Dam) and lagoons. Magni et al. (2008), reports several human interventions to regulate the rivers of the plain of Oristano (Table 8.19). For this reason the score choosen for this variable is 5.



Cabras	Dam construction, digging of the *Scolmatore* channel, elimination of the pond “Stagno Sa Mardini”, water renewal impairment due to barriers, construction of the fish-pond “Sa Mardini”, barriers at “Rio Mare e’ Foghe”.
Mistras	Construction of a fish-pond and aquaculture facilities
Santa Giusta	Separation of the “Pesaria” channel from the Tirso river, direct connection with the sea and construction of a fish catch system; digging and construction of 2 m deep central and peripheral canals; construction of an industrial port and an industrial canal communicating with the sea; construction of a diversion canal of urban wastes.
S’Ena Arrubia	Digging and construction of a central canal and a canal connecting to the sea; construction of various-size barriers and fish-pond.
Corru de S’Ittiri	Construction of barriers and fish-pond.
Marceddì – San Giovanni	Construction of barriers, dams and “*lavorieri*”.

Table 8.19 Main man-made interventions on the lagoons connected to the Gulf of Oristano. (Source: Magni et al., 2008)

Calculation of Susceptibility to Erosion

We can now calculate the Susceptibility sub—factor (SUSC*ero*). In Table 8.20 we report the scores defined for each variable.

Coastal unit	Landform	Artificial frontage	Coastal Slope	Historical Sediment Budget	River Flow Regulation	SUSC*ero*
Mari Ermi Nord	4	1	2	4	5	**3,2**
Mari Ermi Centro	4	1	2	3	5	**3**
Mari Ermi Sud	4	1	1	3	5	**2,8**
Is Arutas	4	1	1	5	5	**3,2**
M.te Corrigas	4	1	4	5	5	**3,8**
Maimoni Nord	4	1	2	4	5	**3,2**
Maimoni Centro	4	1	2	5	5	**3,4**
Maimoni Sud	4	1	2	4	5	**3,2**
Is Coagheddas	4	1	2	3	5	**3**
Promontorio di Seu	2	1	1	1	5	**2**
Funtana Meiga	4	2	2	3	5	**3,2**
San Giovanni	4	1	2	2	5	**2,8**
Istmo Capo San Marco	4	1	2	1	5	**2,6**
Capo San Marco		2	1	1	5	**1,8**
Su Siccu	5	2	2	3	5	**3,4**
Marina di Torregrande	4	4	2	2	5	**3,4**
Sassu	4	3	2	4	5	**3,6**

Marina di Arborea	4	3	5	2	5	**3,8**
Corru S'Ittiri	5	2		2	5	**2,8**
Spiaggia di Marceddi	3	5	5	4	5	**4,4**
Capo Frasca	1	1	1	1	5	**1,8**

Table 8.20 Susceptibility to Erosion for each coastal unit.

We need now to assign a value of susceptibility to the shoreline of the study area and to assign weights to the variables. For ease of calculation, we maintain the same weight for each variable equal to 1/5.

	Variable	Weight
1	Landform (L)	1/5
2	Artificial frontage (A)	1/5
3	Coastal slope (S)	1/5
4	Historical Sediment Budget (B)	1/5
5	River flow regulation (R)	1/5

Table 8.21 Weights of variables.

The Susceptibility is defined by the equation 8.2.

$$SUSC_{ij} = \mathit{l}L_{ij} + \mathit{a}A_{ij} + \mathit{s}S_{ij} + bB_{ij} + rR \tag{8.2}$$

With (i, j) coordinates of the cell, SUSCij Susceptibility factor relative to the cell (i, j), (l, .., r) weights, and (Lij, .., Rij) parameters related to the cell (i, j). The equation is applied to each 10m x 10m cell of the GRID, obtaining for each cell a definite value. As already seen (Section 6.7.1), SUSCero ranges between 1 and 5. The classes defined for SUSCero are reported in Section 6.7.1 (Table 6.17).

8.5.2 Resilience to Erosion

The variables selected to calculate the Resilience sub-factor are: Ecosystems health, Education level, Age of population, Awareness and Preparedness, Risk/Hazard maps, Coastal protection structures

The variables are presented below in detail, and the corresponding classes of Susceptibility are reported in Table B.4 of Appendix B.

Ecosystems health

The ecosystems considered are mainly three: wetlands system, dune systems and Posidonia. In total, about 70% of the seabed of approximately 100 km2 is colonized by Posidonia. In the seabed in front of the Sinis, the distribution of Posidonia varies in function of the morphology and the condition of the substrate. In principle, it can be found in a very good health state. The opinions on the level of quality of other ecosystems is based on recent scientific literature (Costa et *al.*, 2010; Magni et *al.*, 2009; Simeone et *al.*, 2006) combined with expert judgment expressed by the technicians AMP Sinis - Mal di Ventre, interviewed by phone. A score between 1 and 5 is attributed to each relevant ecosystem.

Coastal unit	Type of Shore	Posidonia (1 to 5)	Dune Systems (1 to 5)	Wetlands (1 to 5)	Ecosystems health
Mari Ermi Nord	Beach	5	3	4	**4,0**
Mari Ermi Centro	Beach	5	3	4	**4,0**
Mari Ermi Sud	Beach	5	3	4	**4,0**
Is Arutas	Beach	5	3		**2,7**
M.te Corrigas	Beach	5	4		**3,0**
Maimoni Nord	Beach	5	4		**3,0**
Maimoni Centro	Beach	5	4		**3,0**
Maimoni Sud	Beach	5	4		**3,0**
Is Coagheddas	Beach	5	4		**3,0**
Promontorio di Seu	Cliff	5			**1,7**
Funtana Meiga	Beach	5	2		**2,3**
San Giovanni	Beach	5	3		**2,7**
Istmo Capo San Marco	Beach	5	3		**2,7**
Capo San Marco	Cliff	5			**1,7**
Su Siccu	Beach/Lagoon	5	3	4	**4,0**
Marina di Torregrande	Beach	5	2		**2,3**
Sassu	Beach	5	3	3	**3,7**
Marina di Arborea	Beach	5	3	3	**3,7**
Corru S'Ittiri	Lagoon	5	3	4	**4,0**
Spiaggia di Marceddi	Beach	5	2	3	**3,3**
Capo Frasca	Cliff	5			**1,7**

Table 8.22 Ecosystems health evaluation for every coastal stretch.

For each coastal stretch, we assign the average value between the three scores. In the case of cliffs we consider just the role of the Posidonia as a natural barrier to reduce the wave energy. We present the results in Table 8.26. For every beach shores, the state of the health of existing ecosystems is evaluated. Some of the beaches do not have dunes or wetlands (e.g. Marceddi). The highest values are assigned to those shores presenting all the three ecosystems.

Education level

The values are retrieved from the study of Lattanzio & Associati (2007) and are reported in the Table 8.25 for the 4 municipalities included in the study area.

Municipalities	Education level	Score
Cabras	16 %	2
Oristano	29 %	3
S.Giusta	21 %	2
Arborea	20 %	2

Table 8.23 Education level for the municipalities of the study area.

Age of population

Like for the variable Education Level the values are retrieved from the study of Lattanzio & Associati (2007).

Municipalities	Percentage of population over 65	Score
Cabras	20%	2
Oristano	20%	2
S.Giusta	14%	3
Arborea	17%	2

Table 8.24 Age of population.

Awareness and Preparedness

Regarding this variable, we need a thorough investigation in the area through a statistical analysis of risk perception with respect to a particular hazard. The time and resources did not allow at this stage to carry out the survey and for this reason has been asked whether there were regional civil protection initiatives to inform the local population and economic operators about the potential risks. The feedback has been negative in the sense that stakeholders of the area are neither aware nor prepared to hazard. For this reason, we assign the value 1 to this variable.

Risk/Hazard maps

There are no Erosion Hazard maps. The Environmental Department of the Autonomous Region of Sardinia is preparing a Coastal Plan that it is expected to map coastal erosion. The value is 1.

Coastal protection structures

There are no particular coastal protection structures against erosion. The value is 1.

We need now to attribute the weights to each variable. For the ease of calculation we decide to maintain the same value for each variable.

n.	Resilience variable	Weights
1	Ecosystems health	1/6
2	Education level	1/6
3	Age of population	1/6
4	Awareness and Preparedness	1/6
5	Hazard maps	1/6
6	Coastal protection structures	1/6

Table 8.25 Weights for Resilience to Erosion variables.

8.5.3 Computation of Vulnerability to Erosion

Both the Susceptibility (SUSC) and the Resilience (RES) factors values range between 1 and 5.

Vulnerability is given by the following equation.

$$\mathrm{VULN}ero = \frac{SUSCSero}{RESero}$$

The classe for VULNero are defined in Section 6.7.3 (Table 6.2.1).

We can now calculate the value $\mathrm{VULN}ero_{ij}$ for each cell (I,j) as indicated in the following equation:

$$\mathrm{VULN}ero_{ij} = \frac{\mathrm{SUSC}ero_{ij}}{\mathrm{RES}ero_{ij}}$$

The vulnerability class is assigned to each 10m x 10m cell. We can now draw the vulnerability map that represents the state of the erosion of the coastal system in the absence of Forcing and Hazard.

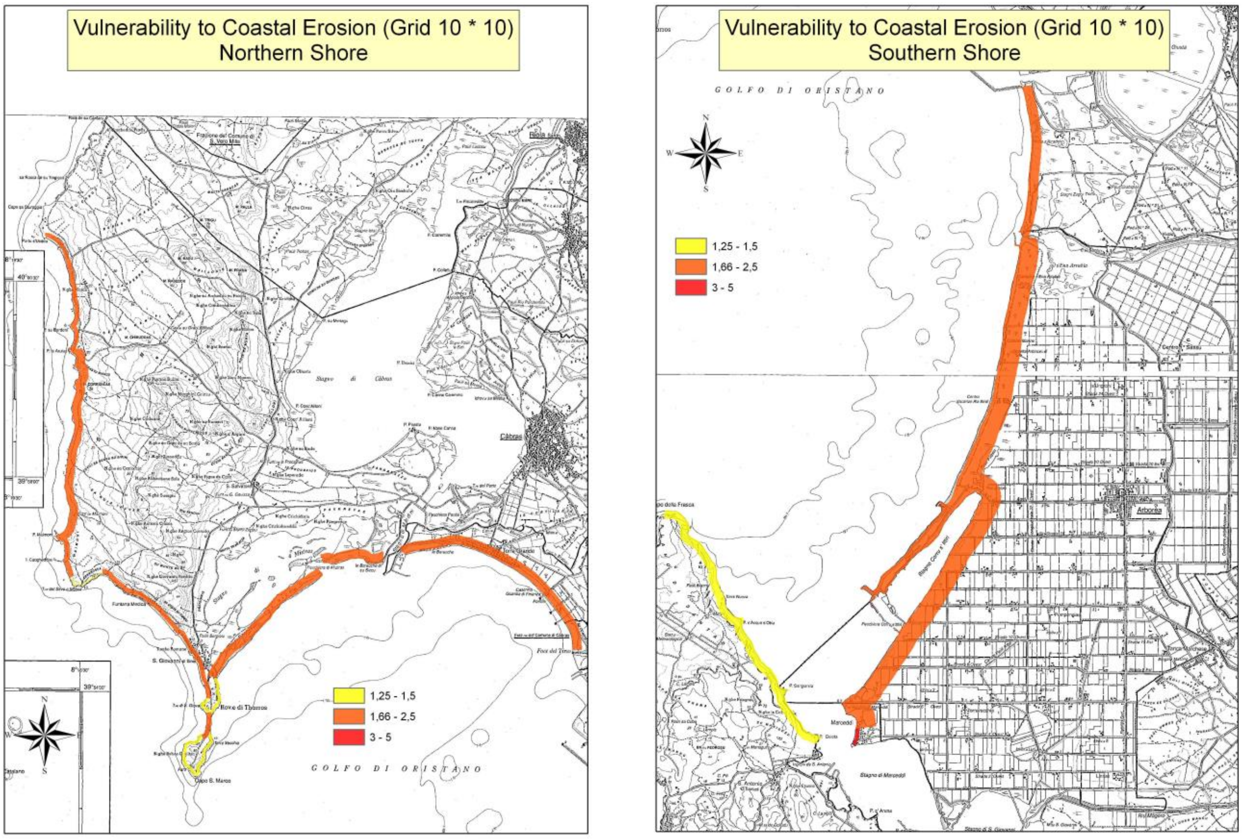


Figure 8.5 Vulnerability to Erosion of the Northern and Southern Shore.

Except for the shoreline presenting high vulnerability (class 3-5) the rest of the beach shores present a moderate vulnerability to coastal erosion (class 1,66–2,5). These results were to be expected as the area in general has a low resilience and high susceptibility.

8.6 Exposure to Erosion

Table E.1 in Appendix E shows the scores for each variable obtained by the expert judgement methodology. The Experts Panel is composed by ten professors of the University of Cagliari, University of Sassari and one researcher of ENEA.

The judgement values are attributed to each 100m x 100m cell of the CORINE LC Grid and then downscaled to a 10m x 10m cell.

8.7 Coastal Erosion Risk Index

The Coastal Erosion Risk Index (CERI) is the result of the following equation:

CERI = FOR*ero* * HAZ*ero* * VULN*ero* * EXP*ero*

We call “stressor” the product FOR * HAZ, which must be attributed to each cells (i,j) of the GRID defined for the study area. The Stressor for the Risk to Erosion function is calculated and presented in Table 8.26.

n.	Coastal unit	Type of Shore	FOR*ero*	HAZ*ero*	Stressor
1	Mari Ermi Nord	Beach	2,32	**0,5**	**1,16**
2	Mari Ermi Centro	Beach	2,32	**1**	**2,32**
3	Mari Ermi Sud	Beach	2,32	**1**	**2,32**
4	Is Arutas	Beach	2,32	**3**	**6,96**
5	M.te Corrigas	Beach	2,32	**1**	**2,32**
6	Maimoni Nord	Beach	2,32	**1**	**2,32**
7	Maimoni Centro	Beach	2,32	**2**	**4,64**
8	Maimoni Sud	Beach	2,32	**1**	**2,32**
9	Is Coagheddas	Beach	2,32	**1**	**2,32**
10	Promontorio di Seu	Cliff	2,32	**1**	**2,32**
11	Funtana Meiga	Beach	2,32	**0,5**	**1,16**
12	San Giovanni	Beach	2,32	**0,5**	**1,16**
13	Istmo Capo San Marco	Beach	2,32	**0,5**	**1,16**
14	Capo San Marco	Cliff	2,32	**1**	**2,32**
15	Su Siccu	Beach	2,32	**2**	**4,64**
16	Marina di Torregrande	Beach	2,32	**3**	**6,96**
17	Sassu	Beach	2,32	**0,5**	**1,16**
18	Marina di Arborea	Beach	2,32	**1**	**2,32**
19	Corru S’Ittiri	Lagoon	2,32	**1**	**2,32**
20	Spiaggia di Marceddi	Beach	2,32	**1**	**2,32**
21	Capo Frasca	Cliff	2,32	**1**	**2,32**

Table 8.26 Stressor to Coastal Erosion.

As seen in Section 6.9, the coastal erosion Risk index values range between 0,05 and 400 and is divided into seven classes (Table 6.26). To calculate the Risk value to each cell (i,j) we multiply the Stressor values assigned to the cells of each coastal unit for the scores of VULN*ero* and EXP*ero* defined for the same cells.We can now draw the Coastal Erosion Risk map through ARCGIS for the Northern Shore and Southern Shore of the Gulf of Oristano.

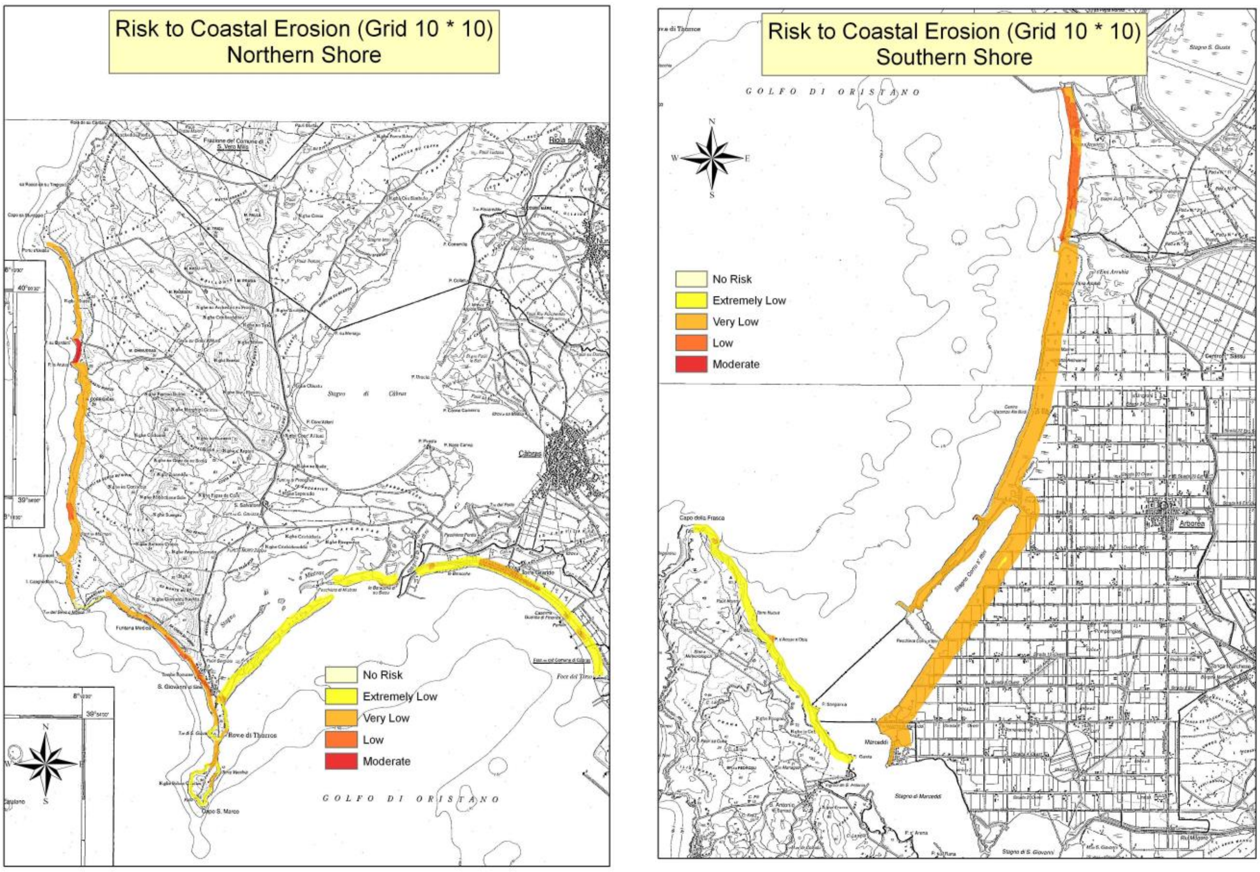


Figure 8.6 Coastal Erosion Risk of the Northern and the Southern Shore of the Gulf of Oristano.

The risk map shows different information than the vulnerability map as the latter includes the variability of exposure, and a multiplying factor that we called stressor. The overlay of the exposure layer, defined by variables that took into consideration both the physical-environmental aspects than socio-economical, reveals very different levels of risk intensity The highest level of risk emerged from the calculation of the risk function is "moderate".

This is obviously due to low levels of forcing and hazard that insist on this coastal area. Areas with moderate risk are: Is Arutas, Funtana Meiga, San Giovanni and Torre Grande. The moderate level of risk of Funtana Meiga, San Giovanni and Torre Grande is mainly due to the presence of these urban settlements close to the dune system.

Regarding Arutas emerges its high environmental value as an element at risk instead. Is Arutas is considered one of the most beautiful beaches of Sardinia and is a high tourist attractor. Surprisingly the shore of Marceddi with high vulnerability presents a very low risk. This is due by the fact that the factor Hazard is low compared to other shorelines. Not surprisingly, the Cliff shores present a very low risk to coastal erosion. It should of course consider that local landslide phenomena, cannot be detected and measured through an index-based method but require more detailed investigations.

8.8 Summary

The Coastal Erosion Hazard Zone (CEHZ) is defined for the Gulf of Oristano

The CEHZ is determined through a specific methodology for this research based on the method applied to New Zealand by Tonkin & Taylor LTD (2004). An assessment of the extent of applicable Hazard Zone takes into account future projections of SLR for 2100. Referring to Leverman, lead author of the sea level chapter for the IPCC's Fifth Assessment Report (IPCC, 2014b), we consider the upper limit of 1.5 meters for SLR. This limit considers the eventuality that sectors of the marine-based ice sheets of Antarctic collapse.

The Climate forcing acting on the Gulf of Oristano is dominated by intense Storms driven by the winds of the fourth quadrant and less by Sea Level Rise component. The Non-Climate forcing is not very relevant because of low Population Average Rate Growth and low to moderate tourism growth.

The Hazard factor is defined as the historical shoreline change (SC). This variable is highly dependent because of different beach and cliff shores conditions. In the 17 beaches of the study area, we observe both phenomena of shoreline erosion than shoreline accretion. The beach of Marceddi shows the highest value of susceptibility. The variables characterizing the resilience factor are of two different types. The first type concerns the variables associated to each of the 17 coastal physiographic units (e.g. the variable ecosystem health), the second type of variables is instead associated to the administrative units represented by the municipalities (Cabras, Oristano, Santa Giusta and Marceddi).

The Exposure variables are evaluated through expert judgement based on a panel of experts defined for this research.

The Risk to coastal erosion values are calculated for each cell (i, j) of the GRID applying the Risk function defined for this study. The results are mapped in a coastal erosion risk map.

What emerges from the map is that Coastal Erosion Hazard for the coastal area of the Gulf of Oristano shows from extremely low to moderate risk.

CHAPTER 9. RISK ASSESSMENT OF THE COASTAL FLOODING HAZARD ZONE

9.1 Introduction

The coastal area of the Gulf of Oristano is strongly affected by the phenomena of inland flooding related to water runoff associated to extreme rainfall events. The combination of extreme rainfall with an extreme marine storm increases the risks for the population, infrastructure and economic activities, in particular in the agricultural sector of the area of Arborea. The phenomena of coastal flooding combined with inland flooding may contribute to the loss of coastal wetlands hydraulic efficiency, to the alteration of river dynamics and salinization of wetlands and groundwater. The strong mistral winds generate a rapid increase of the wave regime in the Gulf of Oristano with the development of waves higher 4.0 meters capable of triggering storms surges, even of medium and high intensity with a locally higher "Run-Up". This phenomenon is more evident in the northern shore of Capo San Marco. The basin of the Gulf of Oristano is more protected from the mistral winds and the related storm surges. To assess the coastal flooding risk of the Gulf of Oristano shoreline, we apply the Coastal Flooding Risk Index (CFRI). We initially proceed to the identification of the coastal flooding hazard zones and then to the definition of the variables of all the factors, which characterize the risk function.

RISK*flood* = f (FOR*flood*, HAZ*flood*, VULN*flood*, EXP*flood*).

Where VULN*flood* is described by SUSC*flood* and RES*flood.*

Physical-environmental variables are attributed to a 10m x 10m cell (e.g. through ARCGIS DEM application). Socioeconomic variables are instead associated to the administrative unit of reference, in most instances the municipalities. Like for the Chapter 8, the unit of reference for the evaluation of Exposure is 10m x 10m cell downscaling from CORINE LC 100m x 100m spatial resolution.

9.2 The Coastal Flooding Hazard Zone

The coastal area of the Gulf of Oristano has a flat morphology. The area of the Bonifica of Arborea is characterized by a number of areas below sea level and the average height is 7 meters above mean sea level. In this specific area, there are a series of swamps depressed, as the former Pond Sassu, now hardened, with an average height of -2 meters above sea level. As presented in Chapter 6 the Coastal Flooding Hazard Zone is calculated with the equation of Hills & Mader

(1997), revisited by Pignatelli et al. (2008) and adapted to the aim of the definition of the coastal flooding hazard zone.

$X_{max} = \frac{TWH^{1,33}}{n^2} * k$

Where

TWH is the Total Water Height

n is the Manning roughness number of the terrain over which the water surges. Developed areas typically have n= 0.030 – 0.035 (Hills & Mader, 1997)

k is a constant number proposed equal to 0.06 for many tsunami (Bryant, 2001)

We need now to define the total water height (TWH) under extreme conditions. With this purpose we introduce propose the following formula including all the potential contributors to generate the Total Water Height:

TWH = SLR100 + SS + RU + FI + U

Where:

SLR100 = Global sea-level rise in cm by the year 2100 as projected by the IPCC AR5. As introduced in Section 8.2.1 we adopt a SLR = 1,5 m

SS = Storm surges measures for 100-years return period. For the Storm surge value we consider a study from Pirazzoli et al. (2007) on the Gulf of Lyon for a return period of 100 years that is a good estimate of the conditions of the western coast of Sardinia. The values estimated in 3 different points are: 0,76, 0,95 and 1,24 m. For this research we consider the average equal to 0,98 m.

RU = Wave Run Up is 70% of Significant Wave Height (MfE of NZ, 2008). For SWH we use the maps produced by Pino et al. (2009) for SWHx95p trend as a proxy for future SWH. The value for western Sardinia ranges between 4,0 and 4,5 m. For precautionary principle we use the maximum value of 4,5 m.

FI = Freshwater Input is the rainfall height ahead of a storm surge that can cause river levels to rise inland from the coast. This freshwater input is measured in the height of the water layer covering the ground in a period of time. In case of extreme rainfall the marine inundation overlaps the freshwater layer. The value of the daily extreme rainfall for a 100-year return period in the area of Oristano is 0,226 m (Deidda et *al*., 1997)

U = uncertainty factor equivalent to 10%

Then

TWH = 1,5 + 0,98 + 4,5 + 0,226 + U = 7,93 m

We can now calculate Xmax using the Pignatelli (2007) formula:

Xmax = $\frac{TWH^{1,33}}{n^2} * k$ = 769 m

Where TWH = 7,93; n = 0,035 and k = 0,06

A more detailed coastal flooding risk and damage assessment would need a more precise calculation of the land roughness induced by vegetation and built environment considered (Kaiser et *al*., 2011). In particular through the use of high-resolution land cover maps and site-specific Manning values for the most prominent land cover classes can be defined allowing a better identification and differentiation of the flooding hazard zones (Kaiser et *al*., 2011). Furthermore the Hazard Zone should also take into account the dominant direction of Storms and then of Winds and their expected variability in future climate change scenarios. We can now draw the Flooding Hazard Zones for the northern and the southern shore of the Gulf of Oristano.

Figure 9.1 Coastal Flooding Hazard Zones. Northern shore (left) and Southern shore (right).

In the two maps is clearly visible the Coastal Flooding setback line as the upper limit of the Hazard Zones. The Coastal Erosion setback line is also indicated in Figure 9.1.

9.3 Forcing to Flooding Hazard

The score for the 4 variables defined in Section 8.3 do not change for Flooding. What changes is the value of weights.

Variable	Score
SLR	3
ST	3
HD	2
TD	3

Table 9.1 Scores for Forcing variables.

For Flooding hazard we can assume that the component of Storms is slightly more relevant than SLR. So we assign 30% to SLR and 70% to ST. The non-climate component of forcing do not play a role for Flooding Forcing and then we consider Whd = Wtd = 0%.

Weights	Value
Wslr	30%
Wst	70%
Whd	0%
Wtd	0%

Table 9.2 Weights for Forcing variables.

The Forcing factor for coastal flooding is calculated as follow:

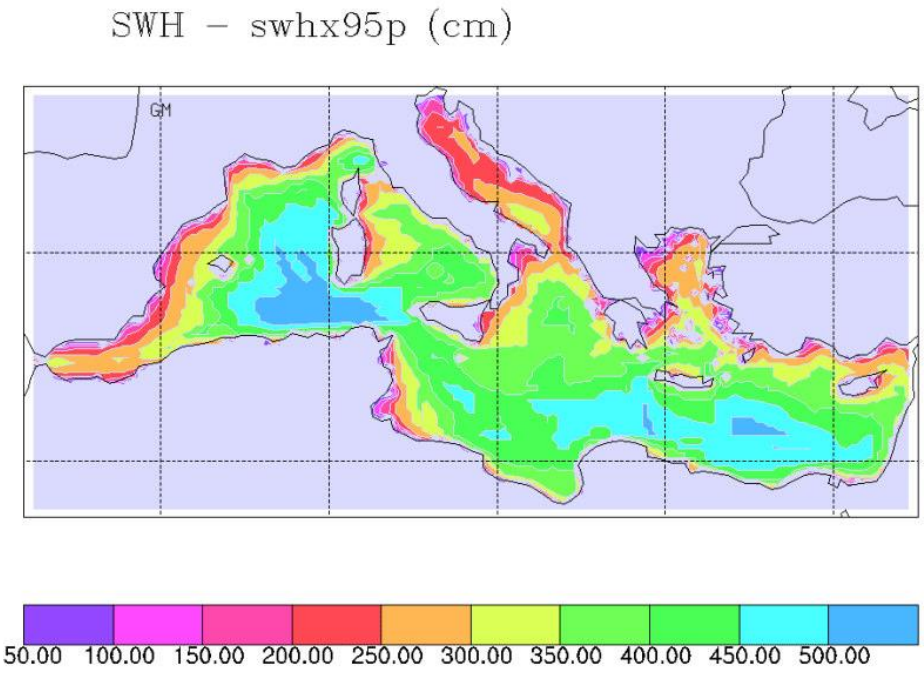
$$\text{FOR}\mathit{flood} = \frac{SLR*wslr+SS*wss+HD*whd+TD*wtd}{5} * 4 = \mathbf{2{,}4}$$

Considering the classed defined for Forcing intensity in Section 6.5.3 (Table 6.10), the score 2,4 represents a moderate level of forcing.

9.4 Flooding Hazard

The Coastal Flooding Hazard is described by the proxy variable SWHx95p, average number of detected Significant Wave Heights above 95 percentile / year.

For the definition of the Flooding Hazard variable for the Gulf of Oristano we refer to the Figure 9.2. The western coastal areas of Sardinia fall in the bright green colour that corresponds to a SWHx95p value that ranges between 4,0 and 4,5 m. According to the scale defined for this research in Section 6.6.2 (Table 6.13), HAZ*flood* correspond to a value of 4 (high intensity of coastal flooding).



SWH – swhx95p (cm)

Figure 9.2 Distribution of SWHx95p (cm) in the Mediterranean. (Source: Pino et *al.* 2009)

9.5 Vulnerability to Flooding

9.5.1 Susceptibility to Flooding

Variables chosen to describe susceptibility to coastal flooding (SUSC*flood*) are: Coastal slope, Elevation, Distance from the shoreline and River flow regulation. The scores for the Susceptibility variables are calculated and assigned to every cell of the GRID defined for the Coastal Flooding Hazard Zone. We propose to modify the classes for the Elevation variable found in the existing literature (Torresan et *al*., 2012) to emphasize the high susceptibility characterizing low lying coastal areas.

The variables are presented below in detail and the corresponding classes of susceptibility are reported in Table B.2 of Appendix B.

Coastal slope

For the costal slope we use the same values that have been calculated for the erosion hazard. Susceptibility classes for flooding variables are the same that for erosion variables. The scores attributed to each coastal stretch are reported in Table 9.3.

n.	Coastal stretch	Costal slope	Score
1	Mari Ermi Nord	9,6	2
2	Mari Ermi Centro	7,1	2
3	Mari Ermi Sud	12,1	1
4	Is Arutas	10,0	1
5	M.te Corrigas	2,9	4
6	Maimoni Nord	7,9	2
7	Maimoni Centro	5,3	2
8	Maimoni Sud	7,8	2
9	Is Coagheddas	9,1	2
10	Promontorio di Seu	23,33	1
11	Funtana Meiga	7,2	2
12	San Giovanni	9,1	2
13	Istmo Capo San Marco	5,6	2
14	Capo San Marco	35,56	1
15	Su Siccu	9,4	2
16	Marina di Torregrande	8,1	2
17	Sassu	7,72	2
18	Marina di Arborea	1,55	5
19	Corru S'Ittiri	1,55	5
20	Spiaggia di Marceddi	1,66	5
21	Capo Frasca	28,89	1

Table 9.3 Slope values for study area coastal stretches.

Elevation

The variable elevation is attributed to each 10m x 10m cell. The areas under 1,5m, the worst SLR scenario defined for this research, will be submerged and even a very low flooding event will strongly impact these areas. Considering that the TWH is 7,92m the areas between 3 and 7 meters have to be considered very susceptible to flooding.

Distance from the shoreline

The variable distance from the shoreline is also applied to each 10m x 10m cell. We use this spatial resolution for a better resolution for the definition of the coastal physiographic units.

River flow regulation

In the case of the coastal flooding hazard, the presence of dams reduces the likelihood of flooding events associated with extreme rainfall and then lowers the relative susceptibility compared to coastal flooding. The area of the Gulf of Oristano was object of important hydraulic works especially on the river Tirso and the area of the Bonifica of Arborea. In general, the whole area is affected by a high river flow regulation. The score is equal to 1. The values are assigned to each 10m x 10m cell..

Computation of Susceptibility to Flooding

We assign different weights to the four variables because the River Flow Regulation contributes indirectly to the coastal flooding susceptibility (i.e. reducing the distance of inland flooding penetration) compared to the other variables.

Variable	Weight
Coastal slope	30%
Elevation	30%
Distance from the shoreline	30%
River flow regulation	10%

Table 9.4 Weighs for Susceptibility variables.

We can now summarize the weighted variables to calculate the Susceptibility to Flooding SUSC*flood*. The variable “Costal Slope” has a mean value for each coastal unit, the variables “Elevation” and “Distance from the Shoreline” attribute values to each 10m x 10m cell measured through ARCGIS. The variable “River Flow Regulation” is the same for all the Flooding Hazard Zone. The classes defined for SUSC*flood* are reported in Section 6.7.1 (Table 6.17).

9.5.2 Resilience to Flooding

The variables selected to calculate the Resilience sub-factor (RES*flood*) are Ecosystems health, Drainage density, Education level, Age of population, Awareness and Preparedness, Risk/Hazard maps, Coastal protection structures.

The variables are presented below in detail, and the corresponding classes of susceptibility are reported in Table B.5 of Appendix B.

Ecosystems health

For the contribution of ecosystems to resilience to coastal flooding the ecosystems considered are the same that for erosion hazard: Wetlands system, the dune systems and Posidonia. The scores associated to each coastal unit are reported in Table 9.5.

Coastal stretch	Type of Shore	Posidonia (1 to 5)	Dune Systems (1 to 5)	Wetlands (1 to 5)	Ecosystems health
Mari Ermi Nord	Beach	5	3	4	**4,0**
Mari Ermi Centro	Beach	5	3	4	**4,0**
Mari Ermi Sud	Beach	5	3	4	**4,0**
Is Arutas	Beach	5	3		**2,7**
M.te Corrigas	Beach	5	4		**3,0**
Maimoni Nord	Beach	5	4		**3,0**
Maimoni Centro	Beach	5	4		**3,0**
Maimoni Sud	Beach	5	4		**3,0**
Is Coagheddas	Beach	5	4		**3,0**
Promontorio di Seu	Cliff	5			**1,7**
Funtana Meiga	Beach	5	2		**2,3**
San Giovanni	Beach	5	3		**2,7**
Istmo Capo San Marco	Beach	5	3		**2,7**
Capo San Marco	Cliff	5			**1,7**
Su Siccu	Beach	5	3	4	**4,0**
Marina di Torregrande	Beach	5	2		**2,3**
Sassu	Beach	5	3	3	**3,7**
Marina di Arborea	Beach	5	3	3	**3,7**
Corru S'Ittiri	Lagoon	5	3	4	**4,0**
Spiaggia di Marceddi	Beach	5	2	3	**3,3**
Capo Frasca	Cliff	5			**1,7**

Table 9.5 Evaluation of Ecosystem Health variable for each coastal stretch of the study area.

Drainage density

The drainage density gives an indication of the drainage capacity of a drainage basin. Tarboton et al. (1992) provide the following definition of Drainage density: Dd = Lt/A. Where Lt is the total length of the streams (drainage channels) in the total basin, and A is the area of a sub-catchment. It reflects the run-off potential of a sub-catchment. The value is calculated through ARCGIS with the Information and Cartographic System of Sardinia Region (Scale 1: 10.000)[26]. The value is 1,33 Km/Km2 according to Table that corresponds to a very high density. Score is 5.

Education level

The values are retrieved from the study of Lattanzio & Associati (2007) and are reported in the Table 9.6 for the four municipalities included in the study area.

Municipalities	Education level	Score
Cabras	16 %	2
Oristano	29 %	3
S.Giusta	21 %	2
Arborea	20 %	2

Table 9.6 Education level for the municipalities of the study area.

Age of population

The values are retrieved from the study of Lattanzio & Associati (2007) and are reported in the Table 9.11 for the 4 municipalities included in the study area.

Municipalities	Percentage of population over 65	Score
Cabras	20%	2
Oristano	20%	2
S.Giusta	14%	3
Arborea	17%	2

Table 9.7 Age of population for the municipalities of the study area.

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[26] Sardegna Geoportale - http://www.sardegnageoportale.it/ (accessed August 5, 2014)

Awareness and Preparedness

Regarding this variable, we need a thorough analysis in the area through a statistical analysis of risk perception with respect to a specific hazard. The time and resources did not allow, at this stage, to carry out a survey on the field. To assign a value to this variable, however, was carried out through direct contact, by telephone, with some representatives of the Civil Protection service of the Sardinia Region and the Province of Oristano. The feedback has been negative in the sense that any capacity building initiative has been carried out in the area that the level of awareness and preparedness is very low according to the interviewed experts. This consideration leads us to assign the value 1 to this variable.

Hazard maps

The Hydrogeological Plan (PAI) prepared in accordance with the Law n. 183/1989 and Decree-Law no. 180/1998, and approved by the Decree of the President of the Region of Sardinia n. 67 of 10/07/2006 is a key regulatory instrument aimed at the conservation, protection of soil, prevention of landslide risk identified on the basis of physical and environmental characteristics of the region. The perimeters identified within the PAI delimit the areas characterized by elements of hydrogeological hazards due to instability of geomorphological or hydraulic issues. The PAI also applies to areas exposed to hydrogeological hazard whose perimeters are derived from studies of the geological, geotechnical and hydraulic compatibility. The PAI exists as a georeferenced database with specific risk and hazard hydraulic maps. Notwithstanding these maps do not refer to the coastal flooding risk, they provide good information for inland flooding risk. The score is 2.

Coastal protection structures

Except the docks of the port areas there are no coastal defence works throughout the study area. The score is 1.In Table 9.8, we report the scores for each variable of Resilience to Flooding (RES*flood*). We use the same weight for each variable.

	Resilience variable	Score	Weight
1	Ecosystems health	Diversified	1/7
2	Drainage density	5	1/7
3	Education level	Diversified	1/7
4	Age of population	Diversified	1/7
5	Awareness and Preparedness	1	1/7
6	Hazard maps	2	1/7
7	Coastal protection structures	1	1/7

Table 9.8 Scores and weights for the Resilience to Flooding variables.

9.5.3 Computation of Vulnerability to Flooding

Both the Susceptibility (SUSC) and the Resilience (RES) values range between 1 and 5. The Vulnerability factor is the result of the following equation.

$$\mathrm{VULN}\mathit{flood} = \frac{SUSCSflood}{RESflood}$$

The classes for VULN*flood* intensity are defined in Section 6.7.3 (Table 6.21).

We can now calculate the value $\mathrm{VULN}\mathit{flood}_{\mathrm{ij}}$ for each cell (I,j) as indicated in the following equation:

$$\mathrm{VULN}\mathit{flood}_{\mathrm{ij}} = \frac{\mathrm{SUSC}\mathit{flood}_{\mathrm{ij}}}{\mathrm{RES}\mathit{flood}_{\mathrm{ij}}}$$

The vulnerability value identified according to the classes of Table 6.21 is assigned to each 10m x 10m cell. We can now draw the vulnerability map that represents the coastal flooding hazard affecting the coastal system of the Gulf of Oristano in absence of Forcing and Hazard.

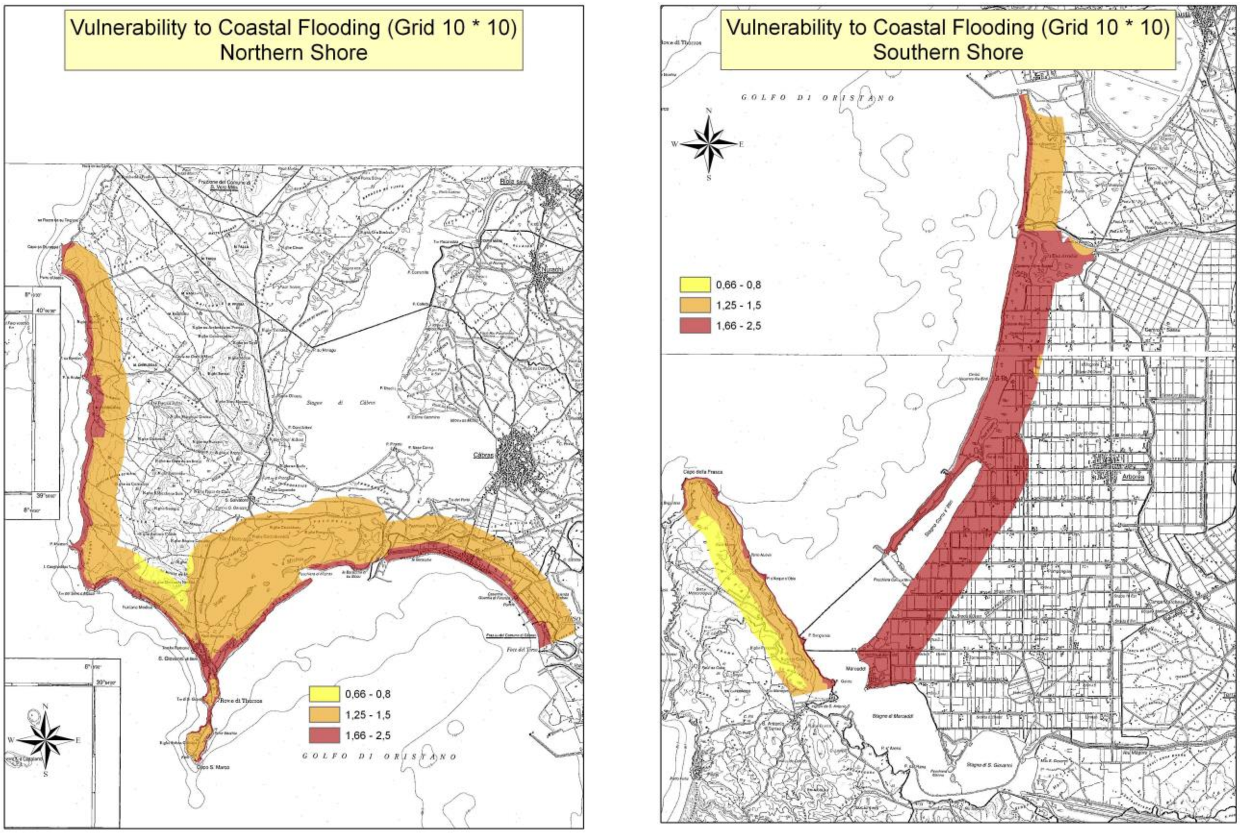


Figure 9.3 Vulnerability to Coastal Flooding of the Northern and the Southern shore of the Gulf of Oristano.

As expected the highest value of vulnerability are nearest the shoreline, and they range between 1,66 and 2,5 intervals corresponding to a very high to high Susceptibility and low to moderate Resilience. This range can be considered as from moderate to high vulnerability. The low-lying coastal areas of the southern shore from Marceddi to Torregrande are interested in moderate vulnerability far inland.

The coastal system of the Gulf Oristano presents a moderate to high vulnerability to coastal flooding notwithstanding the high to very high susceptibility of the low-lying coastal areas. This result is due to the contribution of some Resilience variables like ecosystems health and drainage density, which reduce the mean vulnerability of the area.

9.6 Exposure to Flooding

Table E.2 in Appendix E shows the scores attributed to each variable by the experts of the Experts Panel defied for this research.

The judgement values are attributed to each 100m x 100m cell of the CORINE LC Grid and then downscaled to a 10m x 10m cell.

9.7 Coastal Flooding Risk index

The Coastal Flooding Risk Index (CERI) is the result of the following equation:

CFRI = FOR*flood* * HAZ*flood* * VULN*flood* * EXP*flood*

We call “stressor” the product FOR * HAZ, which must be attributed to each cell (i, j) of the GRID defined for the study area. The Stressor for the Risk to Coastal Flooding is:

FOR*flood* * HAZ*flood* = 2,4 * 4 = 9,6

This value is assigned to every 100m x 100m cell included in the Flooding Hazard Zone. We have already attributed a score to each cell for VULN*flood* and EXP*flood*.

As seen in Section 6.9 (Table 6.25) the CFRI ranges between 0,2 and 400.

To calculate the Risk value to each cell (i,j) we multiply the Stressor values assigned to the cells of each coastal unit for the scores of VULN*ero* and EXP*ero* defined for the same cells.

We can now draw the Coastal Erosion Risk map through ARCGIS for the Northern Shore and for Southern Shore of the Gulf of Oristano according to the classes defined in Table 6.26 of Section 6.9.

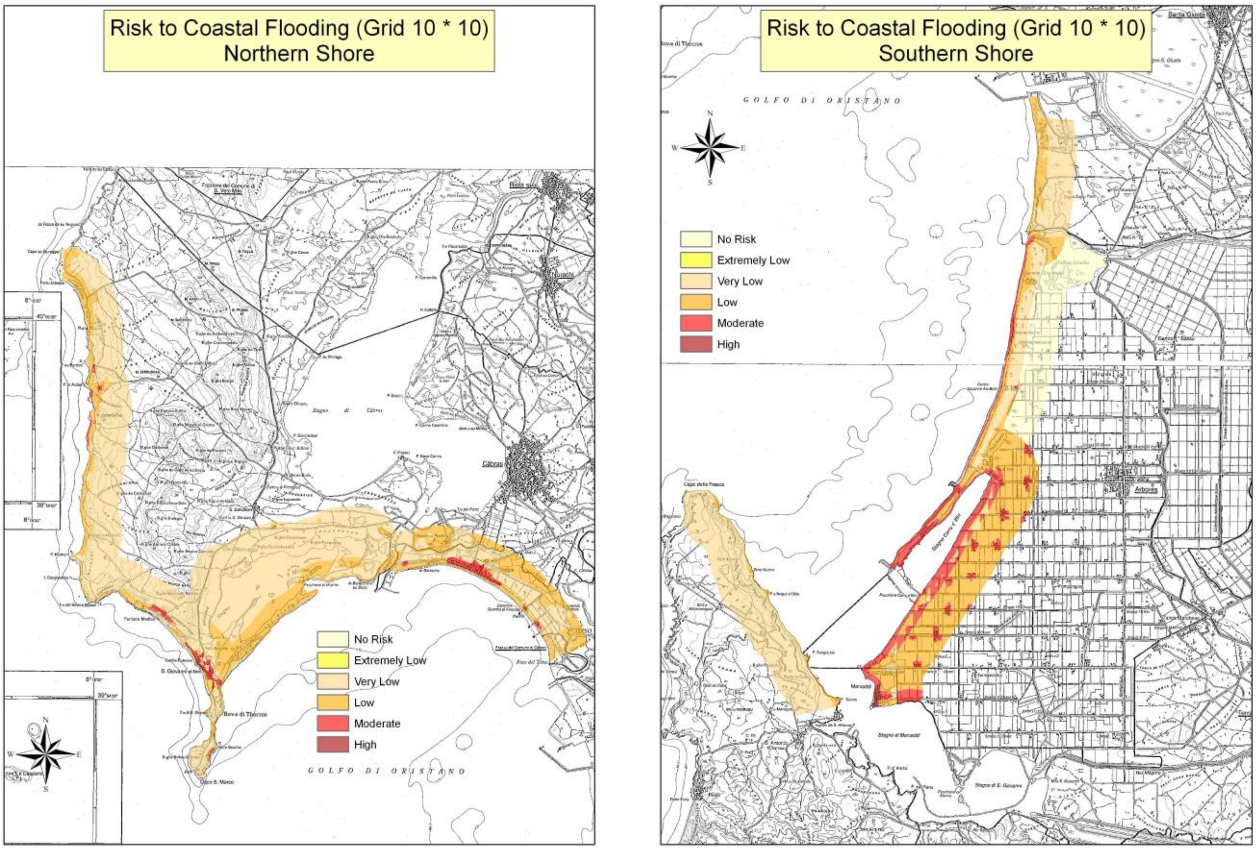


Figure 9.4 Coastal Flooding Risk of the Northern and the Southern shore of the Gulf of Oristano.

As it might be expected, the settlements very close to the shoreline, as the village of Marceddi, present levels of risk to coastal flooding from moderate to high. Other settlements in the municipality of Arborea, even if placed at distances greater than 2km, present a moderate level of risk. This aspect clearly highlights the effects of the variables elevation and coastal slope on the calculation model. The risk level of the entire agricultural plain is not negligible. This result can be attributed to a moderate level of Forcing and Hazard and especially to the lower value assigned to the coastal asset "agriculture" compared to the asset "people and livelihoods".

9.8 Summary

The Coastal Flood Hazard Zone (CEHZ) is defined for the Gulf of Oristano

The CFHZ is defined adapting and adjusting to the Mediterranean context a methodology developed in New Zealand by Tonkin & Taylor LTD (2004). The upper limit of CFHZ, the setback line, is calculated applying the equation of Hills & Mader (1997), revisited by Pignatelli et al. (2008). This equation allows calculating the inland penetration of extreme waves.

The Climate forcing acting on the Gulf of Oristano is dominated by intense Storms driven by the winds of the fourth quadrant and less by Sea Level Rise component. The Non-Climate forcing is limited because of low Population Average Rate Growth and low-moderate tourism growth.

The Coastal Flooding Hazard is described by the proxy variable SWHx95p, the average number of detected Significant Wave Heights above 95 percentile / year.

The variables that contribute the most to the Susceptibility of the coastal system to Coastal Flooding Hazard are Costal Slope, Elevation and Distance from the Shoreline. The variable River Flow Regulation also plays a role reducing the distance of flooding inland penetration.

Resilience variables like ecosystems health and drainage density, present high values for the coastal system of the Gulf of Oristano and can reduce the overall vulnerability of the coast notwithstanding the high susceptibility. The Gulf Oristano presents a moderate to high vulnerability to coastal flooding.

The Exposure variables are evaluated through expert judgement based on a panel of experts defined for this research.

The Risk to coastal flooding values are calculated for each cell (i,j) of the GRID applying the Risk function defined for this research. The results are mapped in a coastal flooding risk map.

The Coastal Flooding Risk map shows a moderate to high risk to some coastal villages settled near the shoreline (e.g. Funtana Meiga, San Giovanni and Marceddi) and a moderate risk to flooding for agricultural settlements. Moderate risk to flooding even at a distance of more than 2km from the coast is due to the low elevation of these areas.

CHAPTER 10. RISK ASSESSMENT OF THE SALTWATER INTRUSION HAZARD ZONE

10.1 Introduction

The area covered by this study, of about 70 km2, includes part of the “Bonifica” of Arborea, which falls in the homonymous municipality, and a small portion of the municipality of Terralba. The area of the Bonifica (reclamation) is limited to the north by the Pond of S'Ena Arrubia and the final stretch of the former Pond Sassu, to the east by the wavy morphology of the volcanic Monte Arci, south of the volcanic complex of Mount Arcuentu, south east from the final stretch of the Rio Flumini Mannu and west by the sea, represented by the line of the Gulf of Oristano (Figure 10.1).

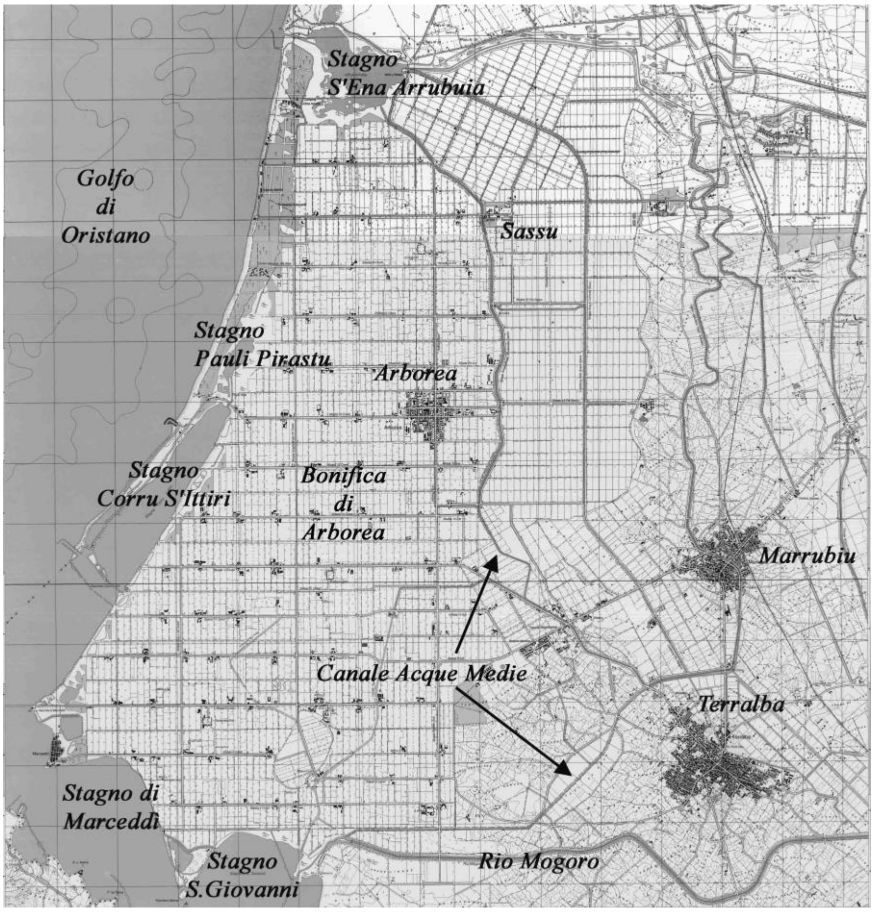


Figure 10.1 The “Bonifica” of Arborea.

The basis for the successful implementation of an Index-based method to assess Saltwater Intrusion risk for coastal aquifer is undoubtedly the availability of comprehensive aquifer datasets. We decide to apply the SWIRI method to the shallow aquifer of the Bonifica of Arborea, because of a complete and long series of data. Nevertheless the data are not always satisfactory, and it is, therefore, necessary to make additional assumptions make data compliant with the method requirements. One important assumption is made, for example, to determine the confinement of the aquifer. Current surveys and available data enable the assessment of the aquifer thickness but are not enough to establish with certainty the real trend of the bed and its lateral confinement. It would have been useful to verify the reliability of these assumptions with updated field investigations (chemical, geophysical, etc.), but this is beyond the scope of this study, and is therefore postponed to future work.

10.2 Definition of the Salt Water Intrusion Hazard Zone

n order to understand and define the hydrogeological total area of the Bonifica of Arborea, and to understand the main mechanisms of groundwater flows, the Water Authority of the Sardinia Region has conducted a campaign of census and sampling of existing wells in the area and conducted a series of in-depth investigations from the period July-December 2001, which have allowed the characterization of the aquifer. Based on this analysis, it is, therefore, possible to identify two aquifers in the territory of the Bonifica of Arborea, a shallow aquifer, and a deep confined aquifer. For the purposes of this study, will analyse only the shallow aquifer that represents the aquifer most used in terms of consumption of freshwater and at the same time the most vulnerable compared to saline intrusion phenomenon as directly in contact with the sea interface. The shallow aquifer is bounded on the north by the Pond S'Ena Arrubia, to the west by the waters of the Gulf of Oristano and the Pond Corru S’Ittiri, on the south by the Ponds of Marceddì and Santa Giusta, the Canal of Acque Medie and a small portion of the Rio Mogoro, and east from the same Canal (Figure 10.2). In the former Pond, Sassu emerges impermeable clay soils, and therefore we do not find the water surface. The bed (bottom) of the water table is very smooth if we exclude the northern fringes, where it was detected in the same study. It can reasonably be said that the shallow aquifer is recharged almost exclusively by the infiltration of rainwater and irrigation. It can reasonably be said that the shallow aquifer is recharged almost exclusively by the infiltration of rainwater and irrigation.

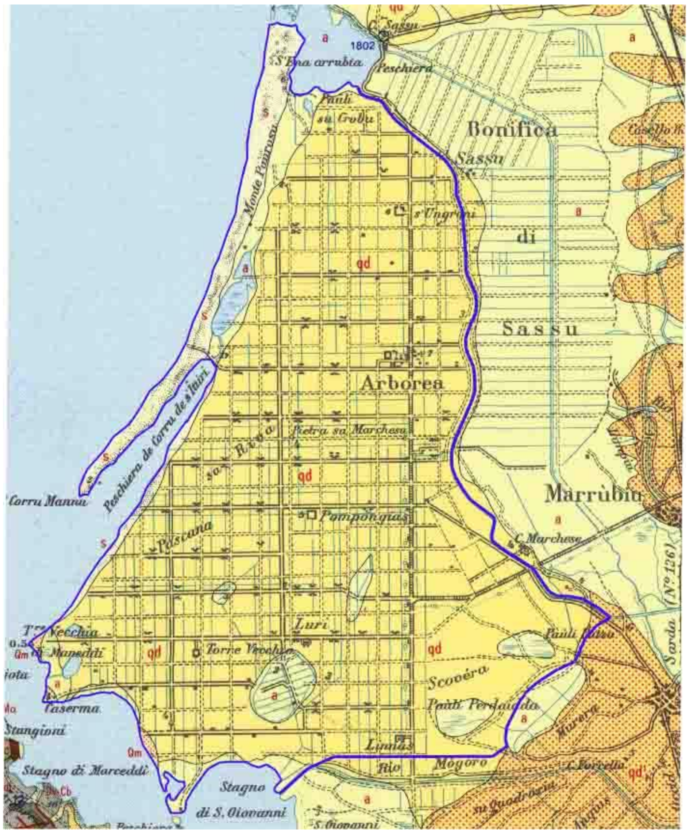


Figure 10.2 Limits of the SWI Hazard Zone.

The single polygon representing the area of interest was built by digitizing its perimeter as a polyline using the ARCGIS software. During the export, the object is associated with its geo-referenced coordinates system according to the Gauss-Boaga.

10.3 Forcing to Salt Water Intrusion

Like for Erosion and Flooding hazard we need to attribute the weights to each component of the Forcing factor.

For the Climate Forcing, we assume that the component of SLR is much more relevant than Storms in affecting the Saltwater Intrusion Hazard as analysed in Section 2.6.3. We assign a weight of 70% to SLR and 10% to ST.

For the Non-Climate Forcing, we have a low population average growth (Table 8.10) for the area of Arborea and a low tourism settlement density mostly concentrated nearby the beach shore. We can consider that in terms of forcing to the groundwater resources, the density of urban settlement, mainly related to the agricultural sector, is more relevant than the forcing of tourism settlements.

We decide to assign a weight of 15% to the HD component and 5% to the TD component. The groundwater resources depletion due to agricultural consumption poses a severe stress to the costal aquifer of Arborea.

We must consider that the area of interest is the coastal aquifer.

Weights	Score
Wslr	70%
Wst	10%
Whd	15%
Wtd	5%

Table 9.9 Weights of Forcing variables.

The value attributed to Forcing to Saltwater Intrusion (FOR*swi*) is:

$$FORswi = \frac{SLR*wslr+ST*wst+HD*whd+TD*wtd}{4} * 5 = \mathbf{2,28}$$

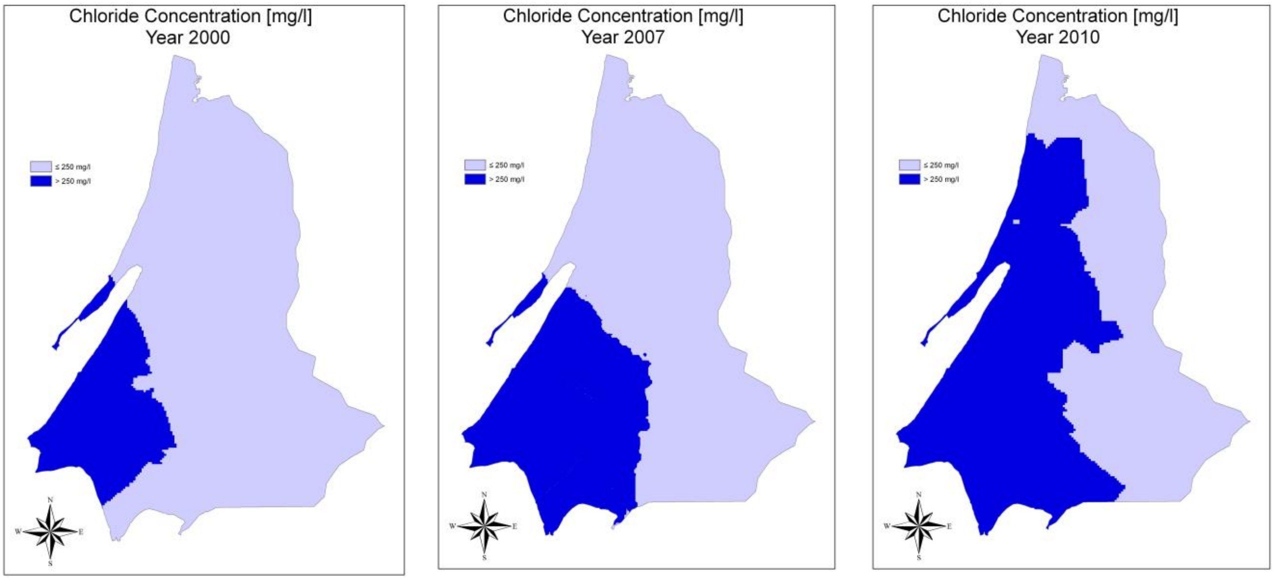
10.4 Salt Water Intrusion Hazard

The Saltwater intrusion hazard is measured as the progress of the salt wedge intrusion in the coastal aquifer.

The variable defined for this research is expressed by the surface of the contaminated aquifer over the total surface of the aquifer measured in specific time span. The SWI Hazard variable represents the speed of Saltwater in intruding the aquifer. The unit of measure is expressed in Km2/y. The interface is the chlorides concentration for drinkable water equivalent to 250 mg/l.

For the shallow unconfined aquifer of Arborea we have three different years of chlorides records: 2000, 2007 and 2010. The Figure 10.2 shows the extension of the groundwater with concentration higher than 250 mg/l.

The maps are obtained by interpolating the values of the chlorides concentrations; values obtained by chemical analysis of water samples taken in 47 wells belonging to the monitoring network of the Autonomous Region of Sardinia (these records are part of the PhD work of Anna Matzeu still in progress). The interpolation was performed through the software ArcGIS using the commands "Spatial Analyst Tools" "Interpolation - Kriging."



Chloride Concentration [mg/l] Year 2000

Chloride Concentration [mg/l] Year 2007

Chloride Concentration [mg/l] Year 2010

Figure 10.3 Chlorides concentration > 250 mg/l in years 2000, 2007 and 2010. (Source: own elaboration).

It can be noticed that the area covered by concentrations of Chlorides over 250 mg/l has increased rapidly in the period between 2007 and 2010. The surface (Scl) with Cl > 250 mg/l is reported in the Table 10.2. The total surface of the aquifer (Saq) is 66,678 km2.

We calculate the percentage of Scl compared to the total surface of the aquifer Saq.

Year	Scl [km^2]	Scl / Saq
2000	12,424	18%
2007	24,636	36%
2010	39,108	58%

Table 10.1 Aquifer area with chlorides concentrations higher than 250 mg/l.

In just 10 years, 40% of the aquifer surface has been interested by saltwater intrusion. In the period between 2007 and 2010 the intrusion has further increased.

We apply now the formula to define the speed of the rate of intrusion that we call SWI_{speed}.

$$SWIspeed = \frac{(Scl)t + n - (Scl)t}{Saq * n}$$

Where n = number of years between the first and the last record of chlorides

SWI_{speed} for the time interval 2000 – 2010 is 3,83 %/year and for the time interval 2007 – 2010 is 7,08 % / year.

As we explained in Chapter 6 there are no benchmarks in the scientific literature so we establish a rate higher to 1 %/y for a very high level of salt wedge intrusion speed that means very high level of SWI hazard.

Level of SWI Hazard	% of Km^2 / y	Score
High	> 1	4
Moderate	0,5 < r ≤ 1	3
Low	0,1 < r ≤ 0,5	2
Very Low	≤ 0,1	1

Table 10.2 SWI Hazard ranking.

The value found for the aquifer of Arborea means that the aquifer is exposed to a high level of SWI hazard (see Table 6.13).

HAZ*swi* = 4

10.5 Vulnerability to SWI

10.5.1 Susceptibility to SWI

The variables selected for the Susceptibility component refer to the GALDIT index developed by Chachadi et al. (2002). Variables chosen to describe susceptibility to coastal flooding (SUSC*swi*) are: Groundwater Occurrence, Hydraulic Conductivity, Height of Groundwater Level above Sea Level, Distance from the shore, Impact of existing status of Seawater Intrusion and Aquifer thickness.

The GALDIT variables have been arranged and adapted for the aims of this research. The corresponding classes of susceptibility defined for each variable are given in Table B.3 of Appendix B. What in the GALDIT method is called “vulnerability” in the present study represents the “susceptibility” factor (SUSC*swi*).

The variables are presented below in detail.

Groundwater occurrence (G)

G represents the type of aquifer. The surface area of the aquifer of Arborea is a phreatic aquifer; set on Quaternary dune sands then is considered an unconfined aquifer. This feature means that the whole area of interest is a single polygon, which is assigned a single record containing the susceptibility class corresponding to the score 4 (Table B.3). We considered the phreatic aquifer of the coastal area of Arborea. We don not consider the other deeper aquifers because of lacking information, as opposed to the most superficial aquifer that is monitored by the Sardinia Region Water Authority, and that is characterized by a consistent database.

Aquifer hydraulic conductivity (**A**)

A represents the hydraulic conductivity. The hypothesis is that the higher the hydraulic conductivity, and therefore water flow speed in the subsoil, the greater the susceptibility of the aquifer to salt intrusion. The whole area falls in the class of maximum susceptibility (> 40) to which is associated a score = 5.

Height of Groundwater Level above the Sea Level (**L**)

L is the depth of the water table. It is assumed that the higher the hydraulic load above the sea level, the lower the susceptibility of the aquifer to salt intrusion since it determines the hydraulic pressure provided to oppose to the front of intrusion.

Distance from the shore (D)

It represents the distance of each point of the aquifer from the shoreline, taken perpendicularly to the same shoreline. The classes of susceptibility of D are built according to the hypothesis that the greater distance from the coast, the lower is the susceptibility to salt intrusion (Chachadi, 2005). The salinization of the aquifer tends to diminish with distance because of the self-decontaminating effect of the ground, both in consequence of the theory of Ghyben-Herzberg. The construction of this last variable, it is done with an ARCGIS tool, “Spatial Analyst Tools” – “Distance”. The tool allows dividing the territory of interest in areas with increasing intervals of distance from the coast. For each area is assigned a susceptibility class and its relative score using Table B.3

Impact of existing intrusion (**I**)

It represents the ongoing contamination of the coastal aquifer. Is evaluated from the knowledge of the following chemicals concentration in groundwater. Cl^- , CO_3^- and HCO_3^- . These concentration values were found as a result of the sampling campaign of The Water Authority of the Sardinia Region (2001-2010). The concentration measurements made in 128 wells (sampling points), evenly distributed in the area, are expressed in mg/l. Regarding the concentration of CO_3^- , there is not a precise value, but sampling indicates, except in one case, the value always less than 3 mg/l. In this situation, it is considered an average value equal to 3 mg/l. For each sampling point, the impact of existing status of seawater intrusion into the aquifer (Ia) is calculated according to the equation: $I_a = \frac{Cl^-}{HCO_3^- + CO_3^-}$. The punctual values of saltwater contamination have been interpolated in the entire area of, thus obtaining a grid of square cells of side equal to 100 meters, for which each cell is assigned a value expressed by the previous equation for I_a. The scores for the variable I_a are shown inn Table B.3, for which it is assumed that the greater the value of I_a, the higher is the contamination and then the susceptibility with respect to that variable. Based on these values, the map for I_a (Figure 10.3) represents the isoconcentration areas of ongoing saltwater contamination. The Figure 10.3 shows that areas with higher susceptibility, that, except in some cases, are located in the proximity of the sea and, partially, of the ponds as expected.

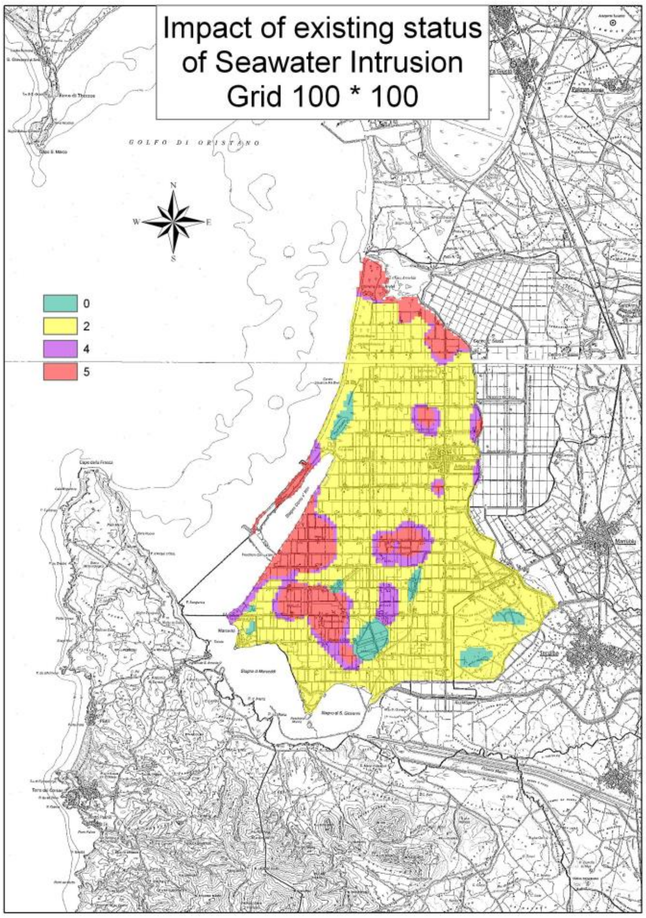


Figure 10.4 Existing saltwater intrusion.

Thickness of the aquifer (T)

This variable is produced as the difference between the layers TOP and BOTTOM of the aquifer. It divides the territory into areas with increasing thickness, which varies between 1 meters until you reach thicknesses greater than 10 meters. In this research it is assumed that the greater the thickness of the aquifer, the greater is the susceptibility. In fact, studies of coastal groundwater aquifers of the coasts of India (Chachadi et *al*., 2002) show that a rise in the sea level, and then to an increase in the thickness of the aquifer corresponds to an increase of susceptibility. This hypothesis also seems to be confirmed by the equation of Ghyben-Herzberg.

The last step before calculating the final value of the aquifer susceptibility of Arborea is to assign weights to the variables. They must give an account of the importance of taking the same parameters within the method, and are established on an empirical basis (Table 10.4). For ease of calculation, we maintain the same weight for each variable equal to 1/6.

	Variable	Weight
1	Groundwater Occurrence (G)	1/6
2	Hydraulic Conductivity (A)	1/6
3	Height of Groundwater Level above Sea Level (L)	1/6
4	Distance from the shore (D)	1/6
5	Impact of existing status of Seawater Intrusion (I)	1/6
6	Aquifer thickness (T)	1/6

Table 10.3 Weight of variables.

The calculation of the susceptibility factor of the aquifer provides that the equation 10.1 is applied to each 100 x 100 cell.

$$SUSC_{ij} = gG_{ij} + aA_{ij} + lL_{ij} + dD_{ij} + iI_{ij} + tT_{ij} + rR_{ij} \tag{10.1}$$

With (i, j) coordinates of the cell, SUSCij susceptibility factor relative to the cell (i, j), (g, r) weights, and (Gij, .., Rij) parameters related to the cell (i, j). The equation 10.1 is applied to each cell of the GRID, obtaining for each of them a different value of susceptibility (Overlay Mapping). SUSC values range between 1 and 5. The classes defined for SUSC*swi* are reported in Section 6.7.1 (Table 6.17). We assign a SUSC value to each cell of the grid, which allows the construction of a layer for each variable. The operation of overlaying the six layers summing the values for each cell, produce as output the final SUSC map shown in Figure 10.4.

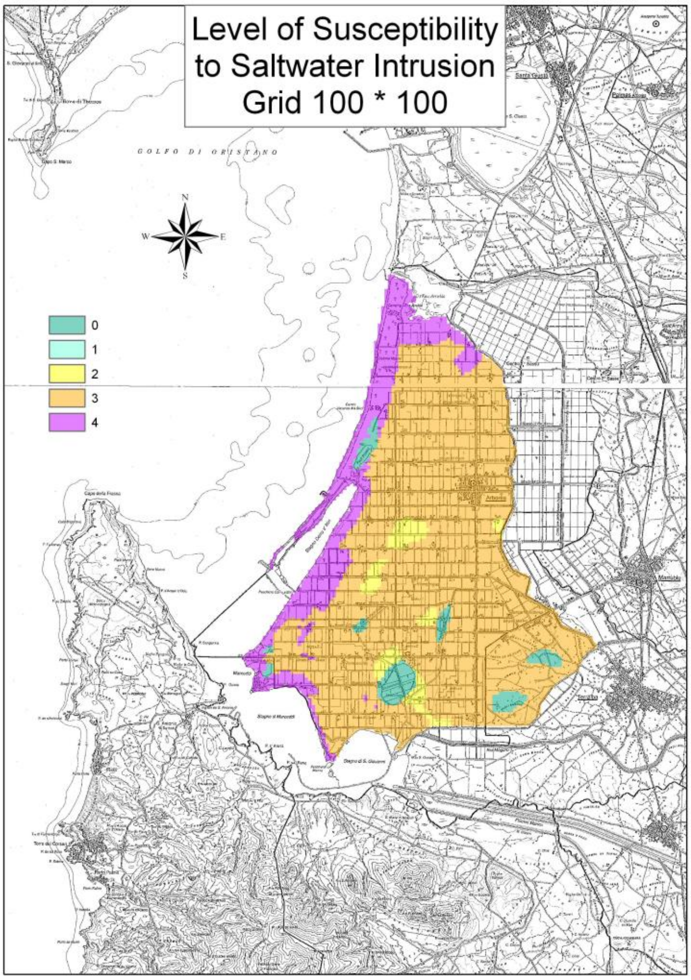


Figure 10.5 Susceptibility to SWI Map.

10.5.2 Resilience to SWI

The variables selected to calculate the Resilience sub-factor for Saltwater Intrusion (RESswi) are: Groundwater consumption, Education level, Age of population, Awareness and Preparedness, Risk/Hazard maps, Freshwater Barrier wells and Water management.

The variables are presented below in detail, and the corresponding classes of susceptibility are reported in Table B.6 of Appendix B.

Groundwater consumption

A current survey of a PhD student of the University of Cagliari (Anna Matzeu, not published yet) carried out in the area Arborea shows that the consumption of the water table is low in proportion, as this does not provide sufficient quantities of water to irrigate the fields. Consequently, the waters of the aquifer are used only for domestic purposes. Estimation of percentage of groundwater consumption uses is 30%. Score is 3.

Education level

The percentage of the population whose level is equal at least to the level 3 of the international standard classification of education (ISCED) is 20% (Lattanzio & Associati, 2007). Score is 2.

Age of population

The percentage of the population over 65 in the territory of Arborea is 17% (Lattanzio & Associati, 2007). Score is 2.

Risk/Hazard Maps

There are no specific maps for saltwater intrusion contamination. Only Nitrates hazard maps exist.

Awareness and Preparedness

The level of awareness and preparedness of the local population and the agricultural sector is feeble, and the public authorities foresee no specific awareness raising activity. This parameter should be better investigated through a specific questionnaire that has not been possible to develop in the course of the research. Score is 1.

Freshwater barrier wells

There are no barrier systems in the area of the aquifer Arborea. Score is 1.

Water management

There is no particular action for water management in the area of Arborea. Score is 1.

The variables are applied to the whole extension of the hazard zone consisting in the area overlying the aquifer that is the territory of Arborea. For ease of calculation, we decide to apply the same weight to the selected variables (1/7).

Variable	Score	Weight
Groundwater consumption	3	1/7
Age of population	2	1/7
Education level	2	1/7
Awareness and Preparedness	1	1/7
Hazard maps	1	1/7
Freshwater Barrier wells	1	1/7
Water management	1	1/7

Table 10.4 Weights for Resilience variables.

The average value for the resilience of the area is 1,57 that is applied to each 100m x 100m cell of the Hazard area. Although the phenomenon of Saltwater Intrusion is a strong environmental problem for the area of Arborea, no concrete action plans aimed at reducing and combating this phenomenon have been implemented.

10.5.3 Computation of Vulnerability to Saltwater Intrusion

Both the Susceptibility (SUSC) and the Resilience (RES) value range between 1 and 5. The Vulnerability factor is the result of the following ratio.

$$\mathrm{VULN}swi = \frac{SUSCSswi}{RESswi}$$

Using the classes of Table 10.10, we can draw a map of vulnerability to Saltwater Intrusion. The vulnerability value is assigned to each 100 x 100 cell. The vulnerability map represents the state of the coastal system in the absence of forcing and hazard. The values for vulnerability ranges between 0.2 and 5. The areas called “No Flux” represent those areas where hydraulic conductivity is zero, and there is no aquifer.

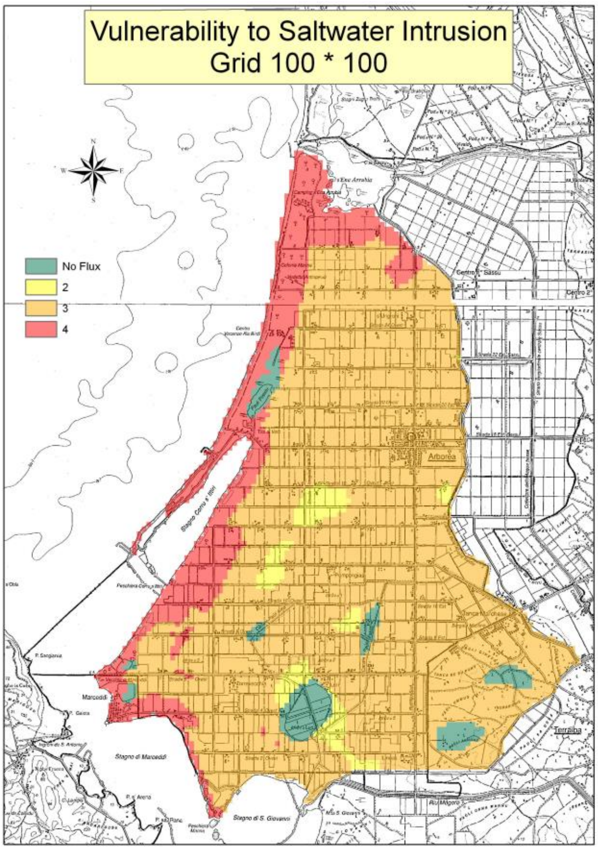


Figure 10.6 Vulnerability to Saltwater Intrusion.

The Map obtained shows that the zones with the highest Vulnerability to Saltwater Intrusion are located in the North and West coastal area (closer to the beach shoreline). In this zone, the soil is formed by alternating layers of gravel and sand, and higher is the density of agricultural and livestock activity. The “No Flux” areas are located in correspondence with marshes.

10.6 Exposure to Saltwater Intrusion

Table E.3 in Appendix E shows the scores assigned to each variable by the experts of the Experts Panel defined for this research. The judgement values are attributed to each 100m x 100m cell of the CORINE LC Grid and then downscaled to a 10m x 10m cell.

The Exposure Map (Figure 10.6) shows that along the coast exposure is very low as there are no land use assets. In the areas near the urban settlements, the exposure variable assumes an average - low value.

Most of the areas is characterized by high values of exposure. These can be found at livestock farms, and agricultural land developed intensively. These coastal assets represent the primary economic activities of the area.

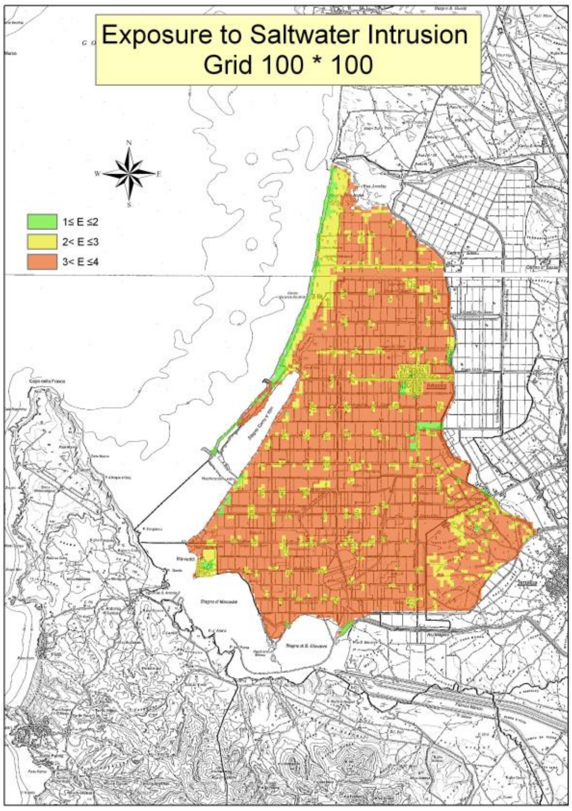


Figure 10.7 Exposure to Saltwater Intrusion.

10.7 SWI Risk Index

The Saltwater Intrusion Risk Index (SWIRI) is the result of the following equation:

SWIRI = FOR*swi* * HAZ*swi* * VULN*swi* * EXP*swi*

We call “stressor” the product FOR * HAZ, which must be attributed to each cells (i,j) of the GRID defined for the study area. The Stressor for the Risk to Saltwater Intrusion is:

FOR*swi* * HAZ*swi* = 2,4 * 4 = 9,6

This value is attribute to every 100m x 100m cell included in the SWI Hazard Zone that coincides with the Surface Aquifer. We have already attributed a score to each cell for VULN*swi* and EXP*swi*.

As seen in Section 6.9 (Table 6.25) the SWIRI ranges between 0,2 and 400.

To calculate the Risk value to each cell (i,j) we multiply the Stressor values assigned to the cells of each coastal unit for the scores of VULN*swi* and EXP*swi* defined for the same cells.

We can now draw the Coastal Erosion Risk map through ARCGIS for the Northern Shore and Southern Shore of the Gulf of Oristano according to the classes defined in Table 6.26 of Section 6.9.

We can now draw the Saltwater Intrusion Risk map through ARCGIS for the Northern Shore and Southern Shore of the Gulf of Oristano according to the classes defined in Table 6.26 of Section 6.9. The Risk map (Figure 10.7) shows a general High Risk value in respect to the phenomenon of Saltwater Intrusion. We could expect this result taking into consideration the high level of current SWI Hazard.

The result, therefore, is an important basis on which to perform actions planning and the protection of this area and be able to make judgments of compatibility between existing activities and the constraints related to the SWI Hazard. This study concerns aspects with a strong interest for the coastal management and planning of the Gulf of Oristano. These issues have not yet been analysed and processed in detail, and which must necessarily be integrated with regional and local planning tools such as PAI (The Regional Hydrogeological Plan).

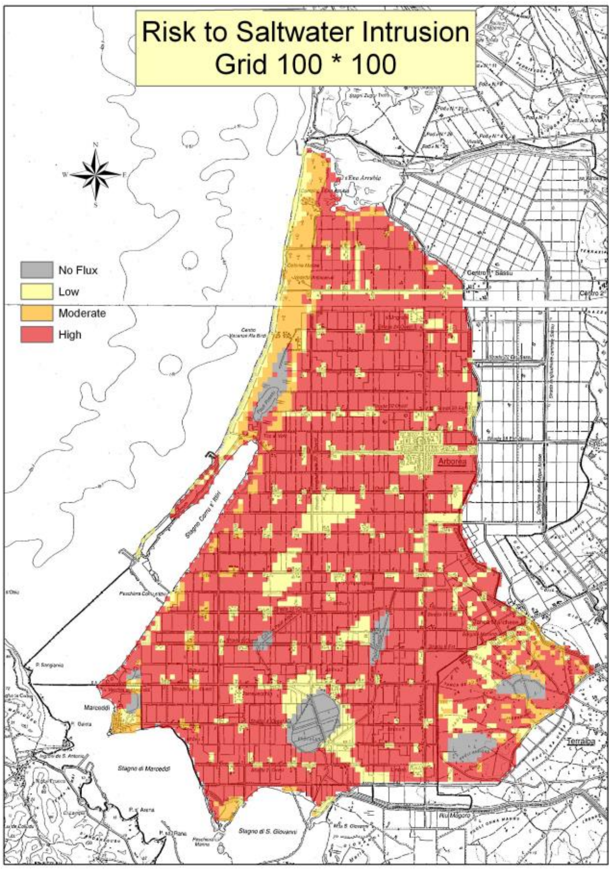


Figure 10.8 Risk to Saltwater Intrusion.

10.8 Summary

The Climate forcing, which more influences Saltwater Intrusion Hazard in the study area, is the Sea Level Rise component. The Non-Climate forcing components are not very relevant for SWI.

The Saltwater intrusion hazard is measured through a variable explicitly defined for this research, which represents the speed of Saltwater in intruding the aquifer. The unit of measure is expressed in Km2/y. The interface is the chlorides concentration for drinkable water equivalent to 250 mg/l.

The Susceptibility to SWI is defined adjusting the GALDIT variables defined by Chachadi et al. (2005). As expected, the Susceptibility map shows that the areas closer to the shoreline (sea interface) present high susceptibility scores and the ponds even very far from the shoreline present moderate susceptibility.

The final score for Resilience is relatively small (i.e. 1,57) notwithstanding the high value of the assets at risk (e.g. agriculture activities).

The Exposure map shows high values for all the study area. This is due again to the presence of livestock farms and agricultural activities representing the main economic activities of the area.

The Risk to Saltwater Intrusion is calculated for each cell (i, j) of the GRID applying the Risk function defined for this research. The results are mapped in a Saltwater Intrusion Risk map.

The Saltwater Intrusion Risk map shows a high risk almost everywhere except in the areas very close to the shoreline. This result shows the limitations of methods like GALDIT that focusing just on physical variables are not able to disentangle the complexity of the interaction between the different components of the system. If we apply the GALDIT Vulnerability Index, we will have found the highest vulnerability values closest to the shoreline and lower values more inland that is exactly the opposite result obtained with the SWIRI.

CHAPTER 11. RISK ASSESSMENT TO MULTIPLE COASTAL HAZARDS

11.1 Introduction

We have applied the Index-based method to each coastal hazard, and we have established the coastal hazard zones for erosion, flooding and saltwater intrusion. The final objective is now to assess the Risk as a result of the 3 combined hazards. We call this integrated index the Multiple Hazards Coastal Risk Index (MHCRI). The field of application of the MHCRI is the coastal portion identified by the overlapping of the hazard zones defined for erosion, flooding and saltwater intrusion. For the application of the MHCRI, we consider just the areas that are contemporary exposed to all the three coastal hazards.

11.2 The Multiple Coastal Hazards Risk Zone

The area of potential risk to multiple hazards is the resultant of the overlay of the hazard zone layers defined for each hazard.

MCHRZ = CEHZ + CFHZ + SWIHZ

Where: MCHRZ = Multiple Coastal Hazards Risk Zone; CEHZ = Coastal Erosion Hazard Zone; CFHZ = Coastal Flooding Hazard Zone and SWIHZ = Saltwater Intrusion Hazard Zone.

As regards the study area taken into consideration, having applied the index SWIRI only to the aquifer of Arborea, the overlay of the CEHZ, CFHZ and SWIHZ, exists only in the intersection between the coastal strip and the shallow aquifer. CEHZ and CFHZ are strictly interconnected as the Flooding Hazard Zone begins in the Erosion Setback Line.

There are just three coastal units that are contemporarily affected by the three hazards namely: “Marina d’ Arborea”, “Corru S’Ittiri” and Spiaggia di Marceddi”. The Multi-Hazards Zone is represented in Figure 11.1, and terms of extension coincide with the Coastal Erosion Hazard Zone. In some ways, it represents the least common multiple between 3 hazard zones.

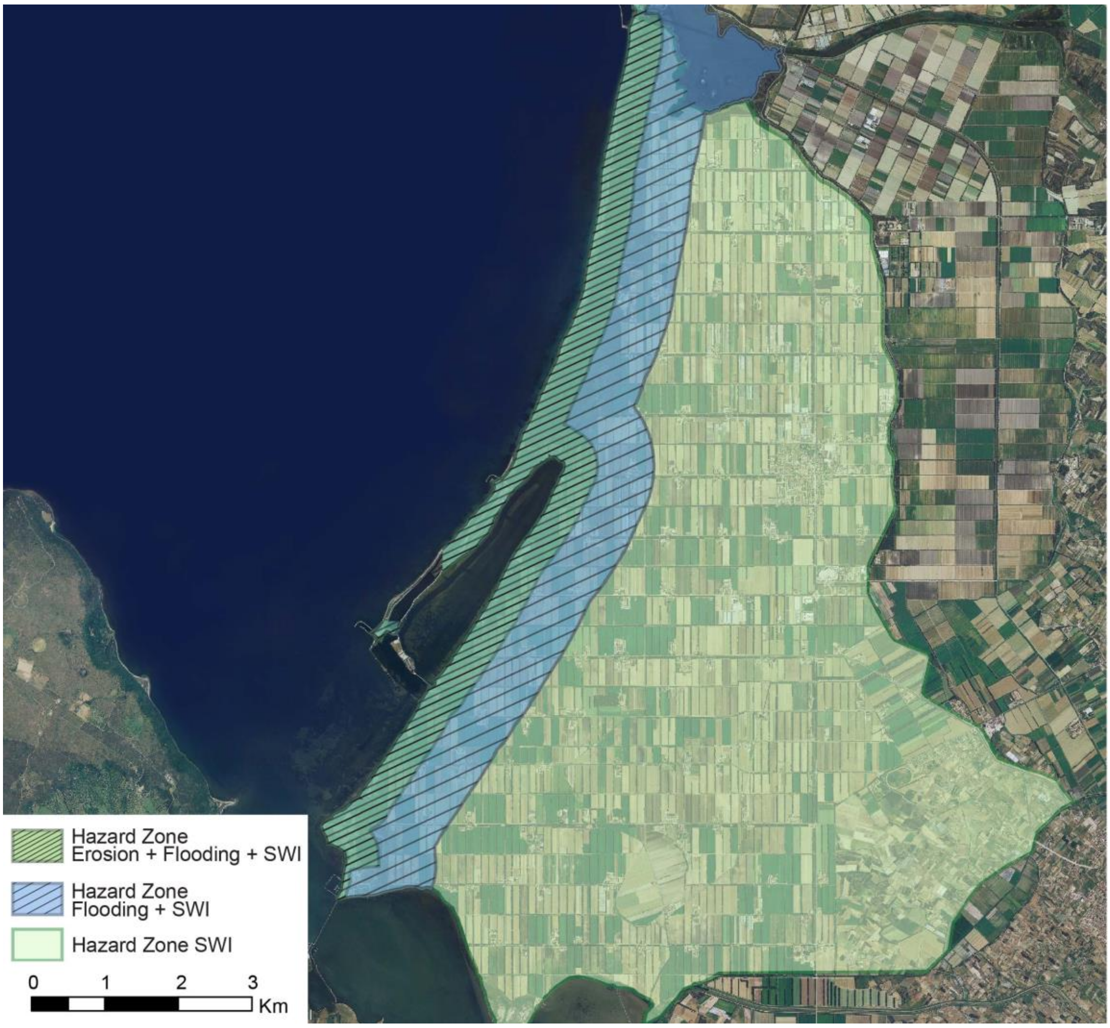


Figure 11.1 Multiple Coastal Hazards Zone.

11.3 Forcing to Multiple Coastal Hazards

The Forcing factor for Multiple Hazards, FOR*mh*, is the mean of the 3 Forcing factors measured for each single hazard.

$$FORmh = \frac{FORero + FORflood + FORswi}{3} = \frac{2{,}32 + 2{,}4 + 2{,}28}{3} = \mathbf{2{,}33}$$

Not surprisingly the mean value 2,33 still represents a moderate forcing (see Table 6.10).

11.4 Multiple Coastal Hazards

We decide to apply the Multiple Hazards Risk Index just to the areas contemporary exposed to the effects of the 3 hazards. The level of Hazard intensity ranges from 1 to 4 (Table 6.13).

We can now summarize the result in terms of Hazard for each coastal unit contemporarily affected by the 3 different hazards (Table 11.1).

Coastal unit	HAZ*ero*	HAZ*flood*	HAZ*swi*	HAZ*mh*	Intensity
Marina di Arborea	1	3	4	**2,67**	**Moderate**
Corru S'Ittiri	1	3	4	**2,67**	**Moderate**
Spiaggia di Marceddi	1	3	4	**2,67**	**Moderate**

Table 11.1 Multiple Hazards factor.

The Multiple Hazards value calculated as the average of the 3 coastal hazards is equal to 2,67 for the 3 coastal units.

11.5 Vulnerability to Multiple Coastal Hazards

The Susceptibility and Resilience variables for the 3 Indices are associated to every 10m x 10m cell. Some variables, like for example River Flow Regulation, presents the same value for the whole study area. Vulnerability is given from the ration of SUSC*mh* and RES*mh*.

$$\mathrm{VULN}mh = \frac{\mathrm{SUSCS}mh}{\mathrm{RES}mh}$$

The classes for VULN*mh* intensity are defined in Section 6.7.3 (Table 6.21).

The value $\mathrm{VULN}mh_{ij}$ is calculated for each cell (i,j) through the following equation:

$$\mathrm{VULN}mh_{ij} = \frac{\mathrm{SUSC}mh\mathrm{ij}}{\mathrm{RES}mh\mathrm{ij}}$$

The value of vulnerability to Multiple Hazards, defined according to the classes of Table 6.21, is assigned to each 10m x 10m cell. We can now draw the vulnerability map for Multiple Hazards as the result of the overlay of the Susceptibility and Resilience maps (Figure 11.2). This map represents the effects of multiple hazards affecting the coastal system of the Gulf of Oristano in absence of Forcing and Hazard.

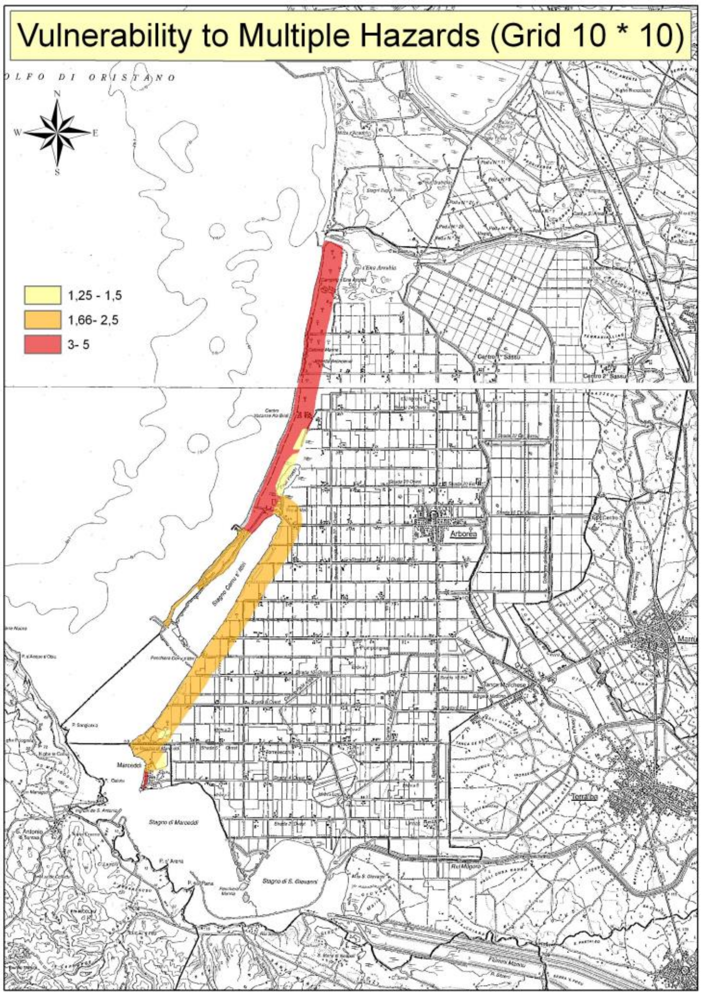


Figure 11.2 Vulnerability to Multiple Hazards.

What emerges from the vulnerability map for multiple hazards is that Marceddi shore confirms a high level of vulnerability. The Marina di Arborea shore, compensate a relative low vulnerability to erosion with relative high vulnerability to flooding and saltwater intrusion resulting in a high vulnerability.

11.6 Exposure to Multiple Coastal Hazards

The Table E.4 in Appendix E shows the average scores for each variable obtained with the expert judgement. The resulting values EXP*mh* are associated to each 100m x 100m cell of the CORINE Land Cover GRID.

11.7 Multiple Coastal Hazards Risk Index

The Multiple Hazard Risks Index (MHZRI) is the result of the following equation:

MHRI = FOR*mh* * HAZ*mh* * VULN*mh* * EXP*mh*

We call “stressor” the product FOR * HAZ, which must be attributed to each cells (i,j) of the GRID defined for the study area. The Stressor for the Risk to Multiple Hazards is:

FOR*mh* * HAZ*mh* = 2,33 * 2,67 = 6,23

This value is attribute to every 100m x 100m cell included in the Multiples Hazards Zone.

We have attributed a score VULN*mh* and EXP*mh* to each cell. To calculate the Risk value to each cell (i,j) we multiply the Stressor values assigned to the cells of each coastal unit for the scores of VULN*mh* and EXP*mh* defined for the same cells.

As seen in Section 6.9 values for MHRI ranges between 0,15 and 400.

We can now draw the final Multiple Coastal Hazards Risk map through ARCGIS.

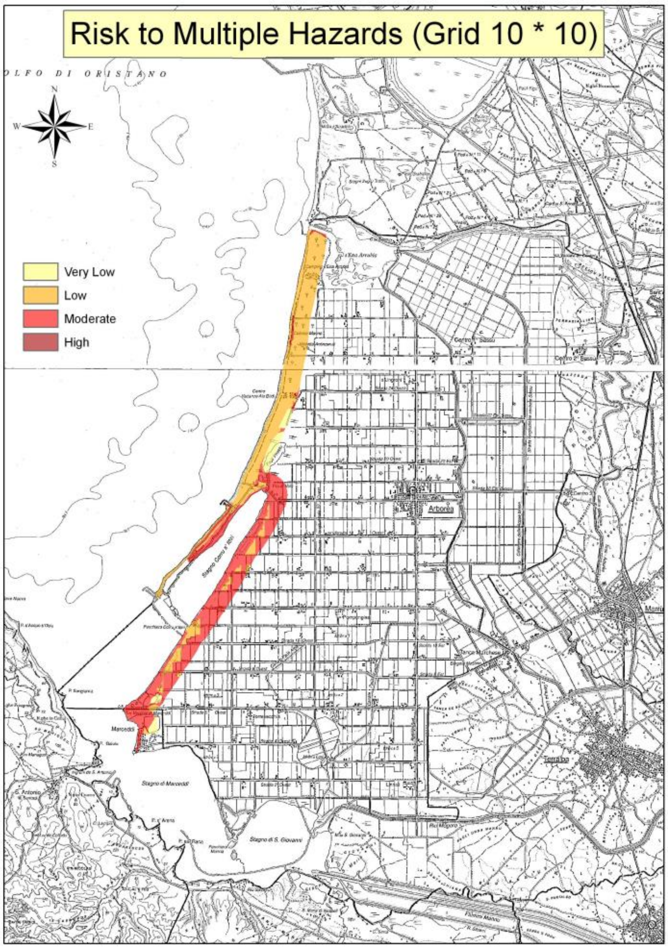


Figure 11.3 Multiple Hazards Risk Map.

The Risk to Multiple Coastal Hazards map seems to represent well the information associated to each single risk map. The forcing parameters are the same for each hazard and also their average values do not affect the final value of MHRI. It should be noted that these values were previously weighted, and these weights are kept unchanged for the implementation of Multiple Hazards Risk Index.

The factor that seems to most influence the final result is Hazard. Moreover, the risk grows faster if the hazard already exists which was one of the preliminary assumptions. To correct the Multiple Hazards index, it would, therefore, be useful to consider the relative weight of the Hazard.

As regards instead the Vulnerability, this is very dependent by the Susceptibility factor (SUSC*mh*) as the Resilience factor (RES*mh*), is almost the same for each hazard and therefore it represents well the overall Resilience for the Multiple Hazards Index.

Regarding the factor Exposure the average value appears to reflect well the mean value assigned to each asset coastal obtained through the Expert Judgment.

11.8 Summary

The final part of this research is to define a method, which considers the interaction of the effects of multiple hazards to the coastal system. The approach recognizes the overlay of the effects of hazards three as the sum of the values assigned to the variables of each index..

The coastal hazard zone for multiple hazards is s given by the common area resulting from the overlay of the layers of the hazard zones defined for erosion, flooding and saltwater intrusion.

The Susceptibility factor for the Multiple Hazards Index (SUSCmh) is the resultant of all the variables describing Susceptibility for each hazard (SUSCero, SUSCflood, SUSCswi). These variables mainly describe the physical characteristics of the coastal zones that are very different from each other according to the hazard, such as an aquifer for saltwater intrusion. This allows us to state that the value of SUSCmh reflects the complexity of the coastal system and the mean value represents well the characteristics of the overall Susceptibility of the coastal system to multiple hazards. The final value of VULNmh as well seems to well represent the average of the values obtained for the Vulnerability values with respect to each Index.

The EXPmh is probably influenced by the view of the experts that had already in mind the need to balance the values assigned to each coastal asset variable among the different hazards.

Further research is needed to disentangle the interaction between different hazards in contributing to the Multiple Hazard index.

CHAPTER 12. CONCLUSIONS

12.1 Introduction

As the globe climate continues to change, coastal communities across the Mediterranean will increasingly be faced with rising sea levels, as well as changes in storm surge frequency and magnitude. Coastal systems are very dynamic and unstable systems that can be rapidly affected by offshore and onshore changes.

Climate changes in combination with anthropogenic driven changes will accelerate existing hazards on Mediterranean coastal zones like erosion, coastal flooding and saltwater intrusion. The estimation of future climate and non-climate changes is uncertain and Mediterranean coastal communities need a high degree of flexibility to enable them to adapt to these changing scenarios.

As a result, decision makers and coastal managers will be confronted with more and more difficult and complex decisions, aiming to identify the best adaptation measures to the social, economic, environmental and political problems generated or exacerbated by these changes.

In this sense, policy makers require adopting an Integrated Coastal Zone Management approach as a credible option to support the decision-making process for a sustainable development of coastal zones.

The main research question is related to where, and how much, these changes will create new coastal hazards or will enhance existing hazards.

This question arises from the need to understand the interactions between climate and non-climate changes, and of coastal systems reactions to these changes in terms of susceptibility and resilience.

In the previous chapters, an innovative Index-based method to assess costal vulnerabilities and risks to multiple hazards is developed and applied to a concrete case study in the Gulf of Oristano in Italy.

This final chapter outlines the research conclusions, and addresses the research objectives (Section 1.2), summarises the thesis contributions (Section 1.3), identifies the limitations and propose rooms for future research (Section 1.4).

12.2 Conclusions

Designing and applying a robust and flexible method to assess vulnerability and risk to climate forcing have challenged researchers in climate change adaptation and disaster risk management field.

One relevant aspect is the disagreement on the theoretical framework behind vulnerability and risk concepts. The main difficulty has been that previous coastal vulnerability and risk assessment studies have based their analysis on different and sometimes contradictory conceptual frameworks. The researchers of the Disaster Risk Reduction and the Climate Change Adaptation streams have often disregarded the need to adopt an integrated approach in the construction of vulnerability assessments methodologies (Romieu, 2010).

The ICZM Protocol has explicitly introduced the need for an integrated and strategic approach in order to ensure the sustainability of coastal areas and to address the broader exigencies of the climate change agenda (Ballinger & Rhisiart, 2011).

The comparative analysis of 26 existing methods to assess coastal vulnerabilities and risks has shown that jus few methods, namely the Index based-methods (e.g. CVI – SLR or Multiscale – CVI) or GIS/computer based methods (e.g. SimCLIM and DESYCO), show high flexibility and adaptability to be applied at different scales and in different Mediterranean coastal zones. Furthermore the analysis showed the need of a method with the following characteristics:

- Based on an internationally recognized vulnerability and risk conceptual framework (e.g. IPCC);
- Assuming an approach based on ICZM;
- Able to properly represent the relevant coastal processes even with limited data availability;
- Based on a multidimensional representation of the coastal zone;
- Adopt a multiple coastal hazard approach;
- Suitable to make comparisons with other Mediterranean coastal regions;
- Easy to use for coastal managers and coastal policy makers.

By considering the uncertain and dynamic nature of the projected changes in climate, as well as to address the non-climate changes in the Mediterranean coastal regions, the aim of the current research was to provide a an integrated method to support coastal managers decisions, incorporating GIS, and Multiple Criteria Decision approaches.

To this aim, an Index-based method to operationalize vulnerability and risk concepts and to create risk profiles to multiple hazards, through the identification and quantification of a set of variables on different scales, has been developed.

The Multiple Hazards Coastal Risk Index (MHCRI) consists of these variables, and through some mathematical combinations an index number is derived for a particular coastal system.

The MHCRI intends to provide decision-makers on local and national level with an effective management tool, helping them to assess and understand the vulnerabilities and the risks a coastal area is exposed.

About this last point, the MHCRI integrates the provisions of the Article 8 of the ICZM Protocol claiming the Mediterranean countries to the definition of a setback area.

The setback areas or coastal hazard zones, are the landward limit of the buffer zone behind the coastline beyond which is defined as an acceptable level of risk produced by coastal hazard. An innovative method for the definition of the Coastal Hazard Zones has been defined and discussed.

The MHCRI is composed by three sub-indices: the Coastal Erosion Risk Index (CERI), the Coastal Flooding Risk Index (CFRI) and Saltwater Intrusion Risk Index (SWIRI). The three indices can also be implemented as stand-alone methods to assess coastal vulnerabilities and risks from a single (e.g. erosion, flooding or saltwater intrusion).

12.3 Thesis contributions

The main objective of the research was the definition of a risk assessment method, to explore how climate and non-climate forcing interact with existing hazards to impact Mediterranean local coastal communities.

The specific objectives of this research are directly related to the features that the coastal risk assessment method must have to satisfy the main objective of the research.

These specific objectives are the following:

- To determine a link between the theoretical and conceptual definitions of risk to climate-related hazards through an integrated assessment approach;
- To explore the possible effects of climate drivers coupled with non climate drivers on coastal hazards;
- To reveal and describe linkages between susceptibility, resilience and exposure concepts of coastal socio-ecological systems as defined by IPCC (2014a) conceptual framework;

- To develop a method to assess the present and the future vulnerabilities and risks, based on various climate and non climate observed trends;
- To compare coastal vulnerabilities and risks of Mediterranean coastal regions and to support the implementation of the ICZM Protocol;
- To produce coastal risk outputs even in conditions of lack of data availability.

The secondary objective was to test the proposed method through its implementation in a concrete Mediterranean case study in order to address the following three questions:

1. What is the present and future risk to climate and non-climate forcing of the coastal zones of the study area in terms of exposure to coastal erosion, costal flooding and saltwater intrusion?

2. What are the potential hazard zones and how can the setback lines be defined?

3. Which are the coastal assets (e.g. people, properties, economic activities, ecosystems) that are more exposed to SLR and storm surges on the study area?

The explanation of how these objectives have been achieved is discussed below:

Chapter 2, 3 and 4 presented the literature review needed to understand climate and non-climate change and their effects on Mediterranean coastal zones, to disentangle the scientific literature on vulnerability and risk concept and to explore the relation between ICZM and Climate Change.

The chapter 3 provided a basis for identifying the gaps in existing vulnerability and risk methodological framework and the need to refer to a common conceptual framework based on the AR5 of IPCC. In chapter 4 emerged the need for Mediterranean countries to be compliant with the ICZM Protocol provision and to define a robust method to define the coastal hazard zones.

Chapter 5 explored the various existing methods for coastal vulnerability and risk assessment.

Index/Indicators based methods, methods based on dynamic computer models, GIS Based Decision Support Tools and Visualization tools have been analysed. The review of the existing methods aimed to verify their compliance with some selecting criteria chosen to identify a suitable method for the Mediterranean coastal zones. The models were assessed for their weaknesses and strengths in order to provide the justification for the selection of a robust modelling approach to be developed for the aim of this research. No Mediterranean integrated methods addressing multiple hazards and climate and non-climate changes were available for vulnerability and risk assessment of coastal zones, nor did any of these methods include the provisions of the ICZM Protocol for the definition of the coastal setback line.

An Index-based method approach was developed in Chapter 6, being based on the on the outputs and the needs defined in Chapters 5. Chapter 6 focussed on the development of the conceptual framework for the definition of the coastal process according to the framework defined by IPCC (2014a; 2014b) for coastal risk. The methodological approach aimed to demonstrate how the functionalities of GIS could be integrated in the building of vulnerability and risk profiles for coastal zones. This result was achieved by exploring the ARCGIS 10.0 software utilities.

Most importantly the proposed method examine the relationships between the impacts of SLR and Storms forcing in combination with the Human induced forcing like coastal population growth and tourism development.

In Chapters 8, 9 and 10, the proposed Index-based approach is tested in the study area of the Gulf of Oristano in Italy. The main characteristics of the area is described in Chapter 7.

The three separates indices for coastal erosion (CERI), coastal flooding (CFRI) and saltwater intrusion (SWIRI) were applied and discussed. The implementation of the proposed Index-based method models involved the assigning of score and weights for the evaluation of coastal assets exposure to hazards carried out by a panel of experts. The developed integrated Index-based method successfully helped to define a robust framework for adequately assessing vulnerabilities and risks of coastal zones to different coastal hazards forced by climate and non-climate drivers.

Chapter 11 presented the implementation of the integrated Index for Multiple Hazards risk assessment (MHCRI). The results showed that the vulnerability and the risk maps produced with ARCGIS are consistent with its conceptual design and confirm the hypothesis.

We can conclude that the proposed Index-based method is robust and capable of reflecting, accurately, the coastal hazard processes and the role of forcing in accelerating existing hazards.

12.4 Limitations and recommendations for future works

This final section highlights the limitations of the developed index-based method and makes some recommendations regarding future research.

One of the main limitations of the model is to consider the average values defined for the regional scale of the Mediterranean basin, to define the variability of the forcing and hazard factors.

Downscaling for the Forcing variables (SLR and Storms) is particularly complex. In addition, while the SLR measurements are made with high-resolution satellite altimetry and more than 20 years time series (since 1992) for Storms there are no regional studies and trends. For the variable Storms, we used a study of Pino et al. (2009), which used SWHx95n as a proxy to measure the extreme storm events. This study has never been published and validated, but the outputs (SWHx95n and SWHx95p) are available as a citation of Lionello (2009). Beyond any doubt, it must be stated that the variable Storms plays a key role as forcing of coastal erosion and coastal flooding. For this reason, it is essential to have regional studies on the Storms variability and trends. Concerning the Hazard variable is possible to calibrate the intensity classes based on local studies or analysis. In the absence of this information, it should be possible to make an assessment in relation to the scale of a macro physiographic unit.

Classes to define the intensity values of hazard are particularly unreliable. They depend very much on the local level. The application of the proposed index-based method in various contexts of the coastal regions of the Mediterranean would allow the refinement of the classes of Forcing and Hazard variables defined on the basis of the existing scientific literature.

Existing land use datasets on the Mediterranean scale are at a scale of 100m x 100m for CORINE LC and 250m x 250m for PEGASO LC. Through ARCGIS is possible to downscale this information with a spatial resolution of 10m x 10m, which allows approximating quite well the coastline and the coastal assets with respect to their exposure to coastal hazards.

When PEGASO LC datasets are validated for the southern shore of the Mediterranean, it will be possible to implement the MHCRI also for those countries that are not covered by CORINE LC.

The results obtained for the definition of coastal erosion and coastal flooding hazard areas, seem to suggest that the setback line of 100 m proposed in the ICZM Protocol, is inadequate to ensure the reduction of risks in a scenario of long-term changes. The setback line cannot be defined in a linear fashion but must take into account the integrated approach including erosion, flooding and saltwater intrusion hazards.

Although the spatial extent for coastal hazard are considered in the model by the definition of the coastal hazard zones, a number of important characteristics of the Storm forcing component were not included, such as the dominant direction of waves impacting the coastal zones. This last aspect is of a crucial importance to better define the limits of the coastal flooding hazard zone.

Future research could investigate the value of coastal assets a risk, such as property values, ecosystems and loss of income, etc.

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APPENDIX A: OVERVIEW OF EXISTING VULNERABILITY AND RISK ASSESSMENT METHODS

Method	Description	Objectives	Compliance with "selecting criteria"	References
BTELSS	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	Considered impacts are: relative sea-level rise, salinity, sediment transport, droughts, rivers discharge and it incorporate ecological and physical assessment targets (ETC CCA, 2011). BTELSS it focuses on wetland; it is applicable to the local scale and even if has been developed for the coastal areas of Louisiana could be exported to the Mediterranean context. BTELSS in quite expensive (ETC-CCA, 2011) and not easy to use as the model requires advanced scientific knowledge and training (McLeod et al, 2010). Outputs are useful for wetlands adaptation measures.	Reyes et al., 2000; Reyes et al., 2004
CanVis	"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."[27]	To simulate potential impacts from sea level rise for the use of coastal decision makers	CanVis simulates potential impacts from sea level rise and coastal development. As the model aims to visualization SLR inundation it doesn't consider socio-economic and ecological assessment targets. The service is freely provided by NOAA and it can be used by local decision makers and local stakeholders for visualize in a very effective way the effects of sea level rise and other impacts.	http://www.csc.noaa.gov/digitalcoast/tools/canvis
CCFVI	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.	The CCFVI considers two Climate Change scenarios: "the best case scenario" and the "worst case scenario". It considers exposure to impacts like sea level rise or storm surge enclosed in the hydrogeological component. CCFVI describes system's vulnerability through the use of indicators. The vulnerable system of CCFVI is the coastal city including the administrative and institutional framework (Balica et al, 2012). In terms of different types of coastal zones CCFVI focus just on large urban areas situated in deltas. It considers natural, social, economic and institutional indicators (Balica et al, 2012). Like other indexes tools is free and easy to use. The CCFVI can be used to support adaptation planning (Balica et al. 2012).	Balica et al., 2012; Nasiri & Shahmohamma-Kalalagh, 2013
Composite Vulnerability Index	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.	The Index assesses coastal vulnerability in general and doesn't refer to climate change projections and impacts except their influence on coastal flooding (ETC-CCA., 2011). It incorporates both socio- economic and ecological aspects. It is applicable at the local scale, and its spatial resolution depends on data availability. It doesn't need specific software and scientific advanced competencies so it's not expensive and relatively easy to use. Its outputs are indices and maps useful for the adaptation planning process.	Szlafsztein & Sterr, 2007
COSMO	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	It assesses different coastal management scenarios included climate change projections and impacts. The model is focused on coastal zone management applications and is tailored for coastal managers also as an educational tool. It can be applied to a different type of coastal zones and to the Mediterranean context even if there is no literature on its application to real contexts. It is not expensive	UNFCCC website; Taal, 2011

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

		measures to respond to climate change impacts.	(150 US $) and easy to use, requires little training, although as a decision support tool it requires more knowledge of physical and socioeconomic characteristics of the coastal area[28]. The tool is designed to be applied as a DSS for coastal management and adaptation planning.	
CVI	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.	CVI is conceived to assess the impacts of sea level rise (e.g. coastal erosion) to the coastal physical system. It doesn't include socio- economic aspects. It can be applied to different coastal zones considering geological and geomorphological characteristics of the coasts. The model is applicable at the local scale of the Mediterranean coastal area (i.e. the model was developed for Turkey). The model it's easy to use and not expensive and it requires some technical knowledge. CVI doesn't provide specific elements for adaptation planning.	Gornitz, 1991; ETC-CCA, 2011
CVI (SLR)	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	CVI (SLR) is an extended version of CVI, and it has all the advantages of CVI with relevant advantages like socioeconomic assessment targets and adaptation measures.	Özyurt, 2007; Özyurt and Egin 2009; ETC-CCA, 2011
DELFT3D MODELLING SUITE	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.	For modeling both natural environments like coastal, river and estuarine areas and more artificial environments like harbors, locks and reservoirs	The Delft3D modelling suite integrates climate change scenarios and different impacts. Assessment targets are mainly the physical coastal system. It's applicable to different coastal zones and at the local scale. It demands high level of site-specific data and expertise that limits its application to more developed countries (ETC-CCA, 2011). It is quite expensive and requires advanced training to be used. Assessment target. It doesn't include adaptation measures.	Deltares website; ETC-CCA, 2011
DESYCO	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	It provides an assessment for different climate change scenarios, and it addresses impacts of sea level rise and storm surge to socio-economic and ecological targets. It can be applied to the different type of coastal zones. It has been applied from regional to sub-national scale, and the spatial resolution can be adapted to data availability (ETC-CCA, 2011). It is integrated with GIS and it's useful to assist coastal managers in adaptation planning. The model needs RRA methodology based on MCDA; Climatic data, DEM//topography, bathymetry, coastline and coastline variations, land cover and land use, geomorphological maps, relevant areas of environmental interest, river and channels maps, protected areas maps, fish farming data (ETC-CCA, 2011).	Torresan et al., 2010 ; ETC-CCA, 2011
DITTY- DSS	The Ditty Decision Support System was developed within the EU project DITTY (Development of an	To assess the influence of	DITTY model doesn't provide climate future scenarios and related impacts. The model is designed for the management of coastal lagoon-watershed systems	Mocenni et al, 2009 ;

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

	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.	watershed basin runoff and the influence of shellfish farming on ecosystem equilibrium and to develop early warning systems.	(ETC CCA, 2011). The scale of application is local. In the output parameters, there are socioeconomic, biological, physical and chemical data. In the drivers of change, it considers socio-economic challenges. It's a useful DSS for coastal managers in lagoon management and adaptation.	ETC-CCA, 2011
DIVA	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	Conducting national assessment of vulnerability in small island nation; Socio-economic and ecological targets	DIVA considers both climate change future scenarios and population growth. It integrated sea level rise impacts (e.g. coastal erosion). It assesses socio-economic and ecological targets. It can be applied to all type of coastal zones. DIVA model has been used at regional or national scale with a spatial resolution of 70km as the smallest. Till now it has never been applied at the local scale. The model requires a very high scientific expertise and is very expensive in terms of scientific expertise for supporting its implementation in a new coastal area. DIVA provides coastal managers with effective adaptation strategies (ETC-CCA, 2011).	Hinkel, 2005; Vafeidis et al, 2008; Hinkel & Klein, 2009; Hinkel et al., 2010; ETC-CCA, 2011
EVA	EVA allows to identify areas alongshore that have demonstrated historic patterns of instability, and currently support valued natural, social, or economic resource[29]. 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	Even if EVA addresses long-term scenario of changes (50 years) it doesn't integrate climate change scenarios. The impacts considered in the model are coastal erosion IT addresses bot socio-economic and ecological vulnerability targets. It is not applicable to different coastal zone and it has been developed only for the Maryland. It is theoretically applicable at the local scale in the Mediterranean context. EVA model provides maps, to inform local stakeholders about potential future risks.	Climate Change Database Clearinghouse, http://www.ccrm.vims.edu/climate_change/misc_other.html (accessed November 4, 2013)
FUND	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.	Economic costs and benefits	Drivers of change are climate change (e.g. sea-level rise), potential dry land and wetland loss. It does not consider social, ecological and physical aspects but just economic aspects. This model is not applicable to different coastal zones. FUND is used to advice policymakers about proper and not-so-proper strategies, but it has a non-user friendly interface and high expertise is required to run the model to obtain useful outputs that are understandable by decision makers. It can be applied only for regional and global scale. It provides information about climate change in a dynamic context, which makes it a useful and innovative tool (McLeod et al., 2010). Adaptation measures are integrated in the model (ETC-CCA, 2011).	Tol; 2006 Tol et al., 2006 Anthoff and Tol, 2009 ETC-CCA, 2011
GVA	It determines the number of people at risk of flooding, loss of coastal wetlands. The model requires changes in flooding caused by storm surges.	global vulnerability assessment of all coastal countries	GVA model considers sea level change but it doesn't consider socio-economical, ecological and physical aspect. It aims to provide a global vulnerability assessment of all coastal countries. It's applicable only at the national scale.	Deltares website

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

HAZUS- MH	Maps delineating hazard characteristics, dollar value of the study region exposure, direct economic losses, essential facility, functionality, shelter requirements and debris.	Estimates potential losses from earthquakes, hurricane winds, and floods.	HAZUS is designed to address natural hazards more than long term climate changes and in particular for earthquakes and hurricanes. It addresses socio-economical and physical impacts and it can be applied at any scale. Hazus is available through online download to users in the United States only. The use of the software requires good technical knowledge of Arc Gis.	www.fema.gov/hazus
InVEST	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[30].	Map and value the goods and services from nature that sustain and fulfill human life.	The model considers sea level rise as driver of change. Its aim is to address nature capital targets (e.g. food, water purification). Outputs include biophysical, economic and social indicators (Rozum & Carr, 2013). InVEST model can be applied to a different scale: global, regional and local. The model needs mapping software such as QGIS or ArcGIS to visualize results, so it is not accessible for not-practitioners.	www.naturalcapitalproject.org/InVEST.html
Multi-Scale - CVI	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	The model considers as drivers of change: forcing variables contributing to wave-induced erosion, (i.e significant wave height, tidal range, storm and modal wave height, storm frequency). Outputs include socio- economical parameters. It can be apply in different typologies of coast (e.g. cliff, sandy beaches) and at different scales: national/regional/local (depending on data availability. It has an easy calculation and no cost except men-hours.	McLaughlin & Cooper, 2010.
RACE	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	Drivers of change are failure of sea defenses and the natural rate of coastal erosion. Socio-economic vulnerability targets are not considered. It can be applied in all types of coastal zones. The scale of this model is both national and local. The spatial resolution depends on data availability. The model it has no user-friendly interface. Risk maps represent a good tool for defining adaptation measures.	Halcrow Group Ltd, 2007
RCVI	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	The most relevant characteristic of this tool is that have been developed specifically for coastal environments with an extreme tide range. RCVI works as an interactive tool for a macrotidal environment that "assesses vulnerability dynamically, with increasing water level" (Tibbetts, 2012). The tool include a specific Wave Exposure Model (WEM) but does not include specific sea level rise projections and climate change scenarios. RCVI just includes physical and ecological assessment targets. It can be applied to different type of costal zones and it provides a coastal classification. It was implement for a local scale case in Nova Scotia.	Tibbetts 2012
RegIS - Regional Impact Simulator	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,	To assess socio-economic and ecological targets	Climate change scenarios are based on outdated regional sea level projections from UKCIP02 scenario31. It includes other drivers like socio economic conditions and changes in land use. Low compliance with the Prerequisite 1. It applies an integrated approach to coastal zone impacts, and it assesses agricultural,	Holman et al., 2005 Richards et al, 2006

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

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

	elevation, land cover, coastal habitats database, existing and proposed sites for managed realignment and tidal surge data.		population and ecosystem vulnerabilities. It does not cover economic impacts (ETC-CCA, 2011). Low compliance with prerequisite 2. It considers all type of coastal systems. Very high compliance with prerequisite 3. RegIS "has been designed for the meta-analysis of the results of offline impacts models" (ETC-CCA, 2011) and to be applied in the Mediterranean scale "offline impacts models would need to be calibrated, and run" (ETC-CCA, 2011). In the input parameters there is lack of DEM information while there are tidal surge data that there are not in our interest, because the study area is located in the Mediterranean sea where tidal are negligible. Low compliance with prerequisite 4. The model has a spatial resolution of 5 km (grid cells) that is still too big for the local scale considered in this research. Low compliance with prerequisite 5. The tool presents a user-friendly interface (ETC-CCA, 2011). Maps and graphs support the coastal decision makers in planning adaptation measures.	
SCAPE	Is a "process-based model that determines the reshaping and retreat of shore profiles along the coast"[32]. 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.	Explore different sea-level rise and wave climate scenarios and protection choices[33]	It addresses different climate change scenarios and sea level rise impacts. It considers socio-economical, ecological and physical aspects. It's applicable to different type of coastal zone. In general SCAPE is only applicable to regional scale. As simulator it aims to give information to policy makers and coastal planners for adaptation.	Pearson et al., 2005 Jude et al., 2005
Sea Level Rise and Coastal Flooding Impacts Viewer	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	It assesses the potential impacts of sea level rise and coastal flooding on coastal resources. It doesn't consider socio- economic and ecological aspects. The main limitation of this model is that it exists only for the U.S. coasts (2013) except Alaska and Louisiana. Is main purpose is to provide comprehensive information to local decision makers and to all stakeholders. The Viewer is free and accessible to everybody. It could be very interesting to export the Viewer to the case of Mediterranean coastal areas.	Sea Level Rise and Coastal Flooding Impacts Viewer | Digital, http://www.csc.noaa.gov/digitalcoast/tools/slrviewer/
SimCLIM	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)	In this model, drivers of change are: relative sea-level rise, climate change (including extreme), inundation areas, social, ecological and economic aspects, local land movements. SimCLIM model considers socio- economical, ecological and physical assessment target. It can be apply in different typologies of coastal zone and in the Mediterranean contest. It is applicable from global to local scale. The tool has a low cost and is user-friendly; training courses are available.	Warrick 2005, 2007 and 2009
SLAMM	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,	To display scenarios of wetland fate and the vulnerability of the coast to sea-	Main driver of change is sea level rise and impacts like coastal erosion and inundation. SLAMM model can be applied to local scale and in different coastal zone type: tidal marsh area, habitat type, wetland areas, dry land, swamp, transitional marsh, marsh, mangrove, beach, flats, open water (McLeod et al.2010). It doesn't include a socioeconomic component (ETC CCA, 2011). Its cost	http://www.slammview.org http://www.warrenpinnacle.com/prof/SLAMM/

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[32] 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).

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

	elevation, slope, aspect; affecting wetlands: inundation, erosion, over wash, saturation, accretion, dikes protected areas.	level rise	is variable (low to medium). Knowledge of GIS is required for raster inputs, minimum high expertise. It provides useful, high-resolution, insights regarding how SLR may impact some coastal habitats (ETC CCA, 2011). Adaptation measures are not addressed by the model (ETC-CA, 2011)	
SMP	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[34]	It provides a large-scale assessment of the risks associated with coastal evolution. It presents a policy framework to address these risks to people and the developed, historic and natural environment in a sustainable manner. The model is free, and it's applicable to different type of coastal areas. It is applicable is only from sub-national to national scale. It requires a high expertise. The adaptation measures are integrated in the model.	Leafe et al (1998) ; Burgess et al (2004)
SoVI®	The Social Vulnerability Index (SoVI®) 2006-10 measures the social vulnerability of U.S. counties to environmental hazards[35]. The data are compiled and processed by the University of South Carolina.	To assess socioeconomic components	The model addresses different environmental hazards but not sea level rise due to climate change, It doesn't consider ecological and physical impacts and it's not applicable at the local scale. It summarizes socioeconomic variables that affect community preparation, response, and recovery from hazards. The model is free.	www.sovius.org

Table A.1 Overview of vulnerability and risk assessment methods.

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

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

Models	Requirements									Fully compliant	Partially compliant
	1	2	3	4	5	6	7	8	9		
	Include SLR projections under different CC scenarios and integrate other key climate change impacts	Incorporate physical, ecological and socio-economical assessment targets	Applicable to different typologies of coastal zone and coastal ecosystems	Applicable to the Mediterranean context	Applicable at the local scale	Not expensive	Easy-to-use	Provide specialized analyses to assist local policy makers in the adaptation planning process.	Outputs of CVA easily to integrate with existing planning		
BTELSS	☺	☺	☺	☺	☺	☹	☹	☺	☺	☺	**7**
CanVis	☺	☹	😐	😐	☺	☺	☺	☺	☺	☺	**5**
CCFVI	☺	☺	☹	☺	☺	☺	☺	☺	☺	☺	**8**
Composite Vulnerability Index	☹	☺	☺	😐	☺	☺	☺	☺	☺	☹	**7**
COSMO	☺	☺	☹	☹	☺	☺	☺	😐	☺	☹	**6**
CVI	☺	☹	☺	☺	☺	☺	☺	☹	☹	☹	**6**
CVI (SLR) -	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	**9**
DELFT3D	☺	☹	☺	☺	☺	☹	☹	☹	☹	☹	**4**
DESYCO	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	**9**
DITTY- DSS	☺	☺	☹	☺	☺	☺	😐	☺	☺	☹	**7**
DIVA	☺	☺	☺	☺	☹	☹	☹	☺	☺	☹	**6**
EVA	☹	☺	☹	☹	☺	😐	😐	☺	☺	☹	**4**
FUND -	☺	☹	☹	☺	☹	☺	☹	☺	☺	☹	**5**
GVA	☺	☹	😐	😐	☹	😐	😐	😐	😐	☹	**1**
HAZUS- MH	☹	☺	😐	☹	☺	☺	☹	😐	😐	☹	**3**
InVEST	☹	☹	😐	😐	☺	😐	☹	😐	😐	☹	**1**
Multi-Scale CVI	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	**9**
RACE	☹	☹	☺	😐	☺	😐	☹	😐	☺	☹	**3**
RCVI	☹	☹	☺	☹	☺	☺	☺	☺	☺	☹	**6**
RegIS	☺	☺	☺	☹	☺	😐	☺	☺	☺	☹	**7**
SCAPE	☺	☺	☺	☹	☹	😐	😐	☺	☺	☹	**5**
Sea Level Rise and Coastal Flooding Impacts Viewer	☺	☹	😐	☹	☹	☺	☺	☺	☺	☹	**5**
SimCLIM	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	**9**
SLAMM	☺	☹	☺	☹	☺	☺	☹	☺	☹	☹	**5**
SMP	☹	☹	☺	☹	☹	☺	☹	☺	☺	☹	**4**
SoVI® -	☹	☹	😐	☹	☹	☺	😐	😐	😐	☹	**1**

Table A.2 Evaluation of the aggregated compliance of the selected tools with the requirements defined for the research.

APPENDIX B: VULNERABILITY VARIABLES

Susceptibility variables

Coastal Erosion									
Coastal sub-system	Variable	Description	Unit	Level of susceptibility to coastal erosion					Source
				1	2	3	4	5	
PE	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		High hard rock sea cliffs	Medium hard rock sea cliffs	Gravel beaches and Sandy shores backed by bedrock & artificial structures	Sandy shores backed by dunes and plains	Coastal lagoon, River delta, saltmarshes	Hammar and Thieler, 2001; Jay et al., 2003; Oziurt, 2007
PE	Artificial frontage	Length of artificial coastline / total coastal length.	%	< 5%	5% - 20%	20% - 30%	30% - 50%	> 50%	EUROSION 2004; Ozjurt 2007
PE	Coastal slope	Is the slope of the coastal region landward and seaward (Oziurt, 2007). It is used to determine the relative risk of the shoreline retreat. Low sloping coastal regions should retreat faster.		> 1/10	1/10 - 1/20	1/20 - 1/30	1/30 - 1/50	1-50 - 1/100	Woodroofe, 2002; Ozyurt, 2007
PE	Historical Shoreline change	Percentage of eroded coast / Sediment budget	%	> 30% in accretion	10% - 30% in accretion		10% -30% erosion	> 30% erosion	Martí et al., 2007; Ozjurt 2007
PE	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	Ozjurt, 2007

Table B.1 Susceptibility variables for Coastal Erosion.

Coastal Flooding									
Coastal sub-system	Variable	Description	Unit	Level of susceptibility to coastal flooding					Source
				1	2	3	4	5	
PE	Coastal slope	Is the steepness or flatness of the coastal region, which is linked to the susceptibility of a coast to inundation by flooding		> 1/10	1/10 - 1/20	1/20 - 1/30	1/30 - 1/50	1-50 - 1/100	Woodroofe, 2002; Ozyurt 2007
PE	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	> 30	30 < el < 20	20 < el < 10	10 < < 5	< 5	Torresan et al, 2012.
PE	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 > 500	500 < d < 300	300 < d < 150	150 < d < 50	d < 50	Ozyurt, 2007
PA	River flow regulation	Dams contribute to reduce inland flow on the sea reducing the overall impact of coastal flooding		dams in the largest tributary		dams only in the minor tributaries		no dams	Nilsson et al., 2005; Ozyurt 2007

Table B.2 Susceptibility variables for Coastal Flooding.

Salt Water Intrusion									
Coastal sub-system	**Variable**	**Description**	**Unit**	**Level of Susceptibility to Saltwater Intrusion**					**Source**
				1	**2**	**3**	**4**	**5**	
PE	Groundwater Occurrence (Aquifer Type)	The extent of seawater intrusion depends on the nature of groundwater occurrence (e.g. an unconfined aquifer under natural conditions would be more affected by seawater intrusion compared to confined aquifer) (Chachadi et al., 2005)	m	Bounded aquifer		Leaky confined Aquifer	Unconfined Aquifer	Confined Aquifer	Chachadi, 2005; Ozyurt, 2007
PE	Aquifer thickness (saturated)	It plays an important role in determining the extent and magnitude of SWI. Larger the aquifer thickness larger the extent of seawater intrusion and vice versa (Chachadi et al., 2005)	m	t < 2,5	2,5 < t < 5	5 < t < 7,5	7,5 < t < 10	> 10	Chachadi, 2005; Oziurt, 2007
PE	Hydraulic Conductivity	Is used to measure the rate of flow of water in the aquifer. Higher the conductivity, higher the inland movement of the seawater fronts (Chachadi et al., 2005) .	m/day	< 5	5 < < 10	10 < <20	20< < 40	> 40	Chachadi, 2005; Oziurt, 2007
PE	Height of Groundwater Level above Sea Level	it determines the hydraulic pressure availability to push back the seawater front (Chachadi et al., 2005).	m	h > 2	2 > h > 1,5	1,5 > h > 1	1 > h > 0,5	h < 0,5	Chachadi, 2005; Oziurt, 2007
PE	Distance from the shore	The impact of seawater intrusion generally decreases as one move inland at right angles to the shore and the creek (Chachadi et al., 2005).	m	d < 100	100 – 400	400 - 700	700 - 1000	d > 1000	Chachadi, 2005; Oziurt, 2007
PE	Impact of existing status of Seawater Intrusion	It determines if the area is under SWI stress and this stress has already modified the natural hydraulic balance between seawater and fresh groundwater (Chachadi et al., 2005).	Range of Cl-/[HCO3-1+ CO3-2], ratio in epm in ground water	< 0,5	0,5 < Cl- < 1	1 < Cl- < 1,5	1,5 < Cl- < 2	> 2	Chachadi, 2005; Oziurt, 2007
PA	River flow regulation	Dams contribute to reduce inland flow on the sea increasing the overall impact of saltwater intrusion		no dams		dams only in the minor tributaries		dams in the largest tributary	Nilsson et al., 2005; Oziurt 2007

Table B.3 Susceptibility variables for SWI.

Resilience variables

Coastal Erosion									
Coastal sub-system	Variable	Description	Measure	Level of the coastal system resilience to coastal erosion					Source
				1	2	3	4	5	
PE	Ecosystems health	A coastal ecosystems 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	Bad (Severe distortions with loss of all species)	Poor (Major distortions)	Moderate (Moderate distortions with loss of 50% of species)	Good (Slight signs of disturbance)	High (No detectable change. All reference species present)	Davey, 2014
SE	Education level	Percentage of population whose level is equal at least to the level 3 of the international standard classification of education (ISCED)	%	< 10%	27 – 10	27 – 43,5	43,5 – 60	> 60%	Barro and Lee (2010)
SE	Age of population	The oldest and the youngest are expected to be the least able to absorb and respond to changes. Data are retrieved from United nations world population prospects[36].	Percentage of population over 65	> 20%	14 – 20	8,5 – 14	3 – 8,5	< 3%	Cutter et al., 2003; Anisimov et al., 2007; Orencio & Fujii, 2013
SE	Awareness and Preparedeness	Perception of living in a hazard risk area. (Yes/Probably/No) and Self-assessed levels of personal preparedness (Likert scale: Not prepared at all – very well prepared)		Not aware Not prepared		Some awareness Moderately prepared		Fully aware Well prepared	Bradford et al., 2012
PA	Risk/Hazard maps			Do not exist		Exist but are not implemented as a legal binding instrument		Exist and are fully implemented as a binding legal instrument	
PA	Coastal protection structures	Artificial protection to erosion.	%	< 5%	5% - 20%	20% - 30%	30% - 50%	> 50%	Ozjurt 2007

Table B.4 Resilience variables for Coastal Erosion.

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[36] UN World population prospect - http://esa.un.org/unpd/wpp/Demographic-Profiles/index.shtm (accessed June 2014)

Coastal Flooding									
Coastal sub-system	Variable	Description	Measure	Level of the coastal system resilience to coastal flooding					Source
				1	2	3	4	5	
PE	Ecosystems health	A coastal ecosystems is healthy whn it functions as a continuum of natural buffer systems protecting against storm surges, flooding and other coastal hazards. Ecosystems include coral reefs, seagrass beds, sand dunes, coastal wetlands and coastal forests.	Ecological status by expert judgement	Bad (Severe distortions with loss of all species)	Poor (Major distortions)	Moderate (Moderate distortions with loss of 50% of species)	Good (Slight signs of disturbance)	High (No detectable change. All reference species present)	Davey, 2014
PE	Drainage density	The drainage density gives an indication of the drainage capacity of a drainage basin. Tarboton et al. (1992) provide the following definition of Drainage density: Dd = Lt/A. Where Lt is the total length of the streams (Drainage channels) in the total basin, and A is the area of a sub-catchment. It is a key indicator as it reflects the run-off potential of a sub-catchment (Vijith & Satheesh, 2006).	m/m2	0.07 - 0.026 lowest density	0.026 - 0.05 low density	0.05 - 0.10 moderate	0.10 - 0.16 dense	0.16 - 0.29 Very dense	Balica, 2012
SE	Education level	Percentage of population whose level is equal at least to the level 3 of the international standard classification of education (ISCED)	%	< 10%	27 – 10	27 – 43,5	43,5 – 60	> 60%	Barro and Lee, 2010
SE	Age of population	The oldest and the youngest are expected to be the least able to absorb and respond to changes. Data are retrieved from United nations world population prospects[37].	Percentage of population over 65	> 20%	14 – 20	8,5 – 14	3 – 8,5	< 3%	Cutter et *al.*, 2003; Anisimov et *al.*, 2007; Orencio & Fujii, 2013
SE	Awareness and Preparedeness	Perception of living in a hazard risk area (Yes/Probably/No) and Self-assessed levels of personal preparedness (Likert scale: Not prepared at all – very well prepared)		Not aware Not prepared		Some awareness Moderately prepared		Fully aware Well prepared	O'Sullivan, 2012
PA	Coastal protection structures	Length of protected coastline / total coastal length.	Expert Judgement by GIS	< 5%	5% - 20%	20% - 30%	30% - 50%	> 50%	Martí et *al.*, 2007; Ozjurt 2007
PA	Risk / Hazard maps	A hazard map highlights areas that are affected of a particular hazard.		Not exist		Exist but are not applied / communicated		Exist and are fully applied / communicated	

Table B.5 Resilience variables for Coastal Flooding.

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[37] UN World population prospect - http://esa.un.org/unpd/wpp/Demographic-Profiles/index.shtm (accessed June 2014)

Saltwater Intrusion

Coastal sub-system	Variable	Description	Measure	Level of the coastal system resilience to saltwater intrusion					Source
				1	2	3	4	5	
PE	Ecosystems health	A coastal ecosystems 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	Bad (Severe distortions with loss of all species)	Poor (Major distortions)	Moderate (Moderate distortions with loss of 50% of species)	Good (Slight signs of disturbance)	High (No detectable change. All reference species present)	Davey, 2014
SE	Groundwater consumption	Ratio of annual groundwater use to annual available groundwater	%	< 20%	20 - 30	30 - 40	40 - 50	> 50%	Oziurt, 2007
SE	Age of population	The oldest and the youngest are expected to be the least able to absorb and respond to changes. Data are retrieved from United nations world population prospects[38].	Percentage of population over 65	< 10%	27 – 10	27 – 43,5	43,5 – 60	> 60%	Cutter et *al.*, 2003; Anisimov et al., 2007; Orencio & Fujii, 2013
SE	Education level	Percentage of population whose level is equal at least to the level 3 of the international standard classification of education (ISCED)	%	> 20%	14 – 20	8,5 – 14	3 – 8,5	< 3%	Barro and Lee, 2010
SE	Awareness and Preparedness	Perception of living in a hazard risk area (Yes/Probably/No) and Self-assessed levels of personal preparedness (Likert scale: Not prepared at all – very well prepared)		Not aware Not prepared		Some awareness Moderately prepared		Fully aware Well prepared	O'Sullivan, 2012
PA	Risk/Hazard maps			Not exist		Exist but are not applied / communicated		Exist and are fully applied / communicated	
PA	Freshwater Barrier wells	Salt water intrusion wells are used to inject water into fresh water aquifers to prevent the intrusion of salt water into the fresh water		Absence				Presence	

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[38] UN World population prospect - http://esa.un.org/unpd/wpp/Demographic-Profiles/index.shtm (accessed June 2014)

PA	Water manage ment	It can consist in modifying pumping patterns or providing direct surface delivery to replace groundwater use by the local water authority. It's related to the existence of a water management authority dealing with groundwater management		Not exists a Water Management Authority		Exists a Water Management Authority but is not active in adapting to SWI		Exists a Water Management Authority and is active in adapting to SWI	Sorensen et *al.*, 1984

Table B.6 Resilience variables for SWI.

APPENDIX C. EXPOSURE VARIABLES

COASTAL SYSTEM COMPONENT	COASTAL ASSET	HAZARD	VARIABLES
Socio-economical	People and livelihoods	Erosion	1.1.1. Continuous urban fabric
			1.1.2. Discontinuous urban fabric
		Flooding	1.1.1. Continuous urban fabric
			1.1.2. Discontinuous urban fabric
		Saltwater Intrusion	1.1.1. Continuous urban fabric
			1.1.2. Discontinuous urban fabric
	Infrastructures	Erosion	1.2.2 Road and rail networks and associated land
			1.2.3. Port areas
			1.2.4. Airports
			1.3.1. Mineral extraction sites
			1.3.2. Dump sites
			1.3.3. Construction sites
		Flooding	1.2.2. Road and rail networks and associated land
			1.2.3. Port areas
			1.2.4. Airports
			1.3.1. Mineral extraction sites
			1.3.2. Dump sites
			1.3.3. Construction sites
		Saltwater Intrusion	1.2.2 Road and rail networks and associated land
			1.2.3. Port areas
			1.2.4. Airports
			1.3.1. Mineral extraction sites
			1.3.2. Dump sites
			1.3.3. Construction sites
	Industrial or commercial units	Erosion	1.2.1. Industrial or commercial units
		Flooding	1.2.1. Industrial or commercial units
		Saltwater Intrusion	1.2.1. Industrial or commercial units
	Socio-Cultural assets	Erosion	1.4.1. Green urban areas
			1.4.2. Sport and leisure facilities (including archaeological sites)
		Flooding	1.4.1. Green urban areas
			1.4.2. Sport and leisure facilities (including archaeological sites)
		Saltwater Intrusion	1.4.1. Green urban areas
			1.4.2. Sport and leisure facilities (including archaeological sites)
	Agriculture	Erosion	2.1.1. Non-irrigated arable land
			2.1.2. Permanently irrigated land
			2.1.3. Rice fields
			2.2.1. Vineyards
			2.2.1. Fruit trees and berry plantations
			2.2.1. Olive groves
			2.3.1. Pastures
			2.4.1. Annual crops associated with permanent crops
			2.4.2. Complex cultivation patterns

			2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation
			2.4.4. Agro-forestry areas
		Flooding	2.1.1. Non-irrigated arable land
			2.1.2. Permanently irrigated land
			2.1.3. Rice fields
			2.2.1. Vineyards
			2.2.1. Fruit trees and berry plantations
			2.2.1. Olive groves
			2.3.1. Pastures
			2.4.1. Annual crops associated with permanent crops
			2.4.2. Complex cultivation patterns
			2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation
			2.4.4. Agro-forestry areas
		Saltwater Intrusion	2.1.1. Non-irrigated arable land
			2.1.2. Permanently irrigated land
			2.1.3. Rice fields
			2.2.1. Vineyards
			2.2.1. Fruit trees and berry plantations
			2.2.1. Olive groves
			2.3.1. Pastures
			2.4.1. Annual crops associated with permanent crops
			2.4.2. Complex cultivation patterns
			2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation
			2.4.4. Agro-forestry areas
Physical-Environmental	Forests	Erosion	3.1.1. Broad-leaved forest
			3.1.2. Coniferous forest
			3.1.3. Mixed forest
		Flooding	3.1.1. Broad-leaved forest
			3.1.2. Coniferous forest
			3.1.3. Mixed forest
		Saltwater Intrusion	3.1.1. Broad-leaved forest
			3.1.2. Coniferous forest
			3.1.3. Mixed forest
	Seminatural areas	Erosion	3.2.1. Natural grassland
			3.2.2. Moors and heathland;
			3.2.3. Sclerophyllous vegetation
			3.2.4. Transitional woodland/shrub
			3.3.1. Beaches, dunes, sands
			3.3.2. Bare rock
			3.3.3. Sparsely vegetated areas
			3.3.4. Burnt areas
		Flooding	3.2.1. Natural grassland
			3.2.2. Moors and heathland
			3.2.3. Sclerophyllous vegetation
			3.2.4. Transitional woodland/shrub

			3.3.1. Beaches, dunes, sands
			3.3.2. Bare rock
			3.3.3. Sparsely vegetated areas
			3.3.4. Burnt areas
		Saltwater Intrusion	3.2.1. Natural grassland
			3.2.2. Moors and heathland;
			3.2.3. Sclerophyllous vegetation
			3.2.4. Transitional woodland/shrub
			3.3.1. Beaches, dunes, sands
			3.3.2. Bare rock
			3.3.3. Sparsely vegetated areas
			3.3.4. Burnt areas
	Wetlands	Erosion	4.1.1. Inland marshes
			4.1.2. Peatbogs
			4.2.1. Salt marshes
			4.2.2. Salines
			4.2.3. Intertidal flats
		Flooding	4.1.1. Inland marshes
			4.1.2. Peatbogs
			4.2.1. Salt marshes
			4.2.2. Salines
			4.2.3. Intertidal flats
		Saltwater Intrusion	4.1.1. Inland marshes
			4.1.2. Peatbogs
			4.2.1. Salt marshes
			4.2.2. Salines
			4.2.3. Intertidal flats
	Water bodies	Erosion	5.1.1. Water courses
			5.1.2. Water bodies
			5.2.1. Coastal lagoons
			5.2.2. Estuaries
		Flooding	5.1.1. Water courses
			5.1.2. Water bodies
			5.2.1. Coastal lagoons
			5.2.2. Estuaries
		Saltwater Intrusion	5.1.1. Water courses
			5.1.2. Water bodies
			5.2.1. Coastal lagoons
			5.2.2. Estuaries

Table C.1 Categories of coastal assets representing Exposure variables (Source: own elaboration based on CORINE LC classes).

APPENDIX D. EXPERTS PANEL

Expert	**Title**	**University / Research Centre**	**Specialization**	**Hazard competency**			**Coastal asset competency**								
				Erosion	Flooding	SWI	People and livelihoods	Infrastr.	Industrial or commercial units	Socio-Cultural assets	Agricult.	Forests	Seminat. areas	Wetlands	Water bodies
1	Professor	University of Sassari	Ecology, Coastal Ecosystems, Fishery	1	1	3	1	1	1	1	1	2	2	3	3
2	Professor	University of Sassari	Coastal erosion, coastal flooding, climate change,	3	2	1	1	1	1	1	1	1	2	2	2
3	Professor	University of Cagliari	Hydrogeology and Risk	1	2	3	1	1	1	1	1	1	1	2	3
4	Professor	University of Cagliari	Hydrogeology	1	1	3	1	1	1	1	1	1	1	2	3
5	Professor	University of Sassari	Coastal ecosystem and Agriculture	1	1	2	1	1	1	1	3	3	3	2	1
6	Professor	University of Cagliari	Coastal geology and geomorphology	2	2	2	1	1	1	2	1	2	2	3	3
7	Professor	University of Cagliari	Geology, geography, impact assessment, tourism and water management	1	1	2	2	2	2	2	1	2	2	2	2
8	Professor	University of Cagliari	Tourism, Local Development and Marketing	1	1	1	3	3	3	3	2	1	1	1	1
9	Professor	University of Sassari	Physical Geography, Geomorphology, Coastal erosion, archaeology	3	1	2	1	1	1	2	1	1	2	2	2
10	Researcher	ENEA	Coastal erosion	3	2	3	1	1	1	1	2	2	2	2	2

Table D.1 Experts Panel and related scores.

APPENDIX E. WEIGHTS OF EXPOSURE VARIABLES

COASTAL EROSION		
COASTAL ASSET	VARIABLE	SCORE
People and livelihoods	1.1.1. Continuous urban fabric	4,8
	1.1.2. Discontinuous urban fabric	3,7
Infrastructures	1.2.2 Road and rail networks and associated land	4,1
	1.2.3. Port areas	4,2
	1.2.4. Airports	3,6
	1.3.1. Mineral extraction sites	2,2
	1.3.2. Dump sites	2,5
	1.3.3. Construction sites	2,9
Industrial or commercial units	1.2.1. Industrial or commercial units	4,5
Socio-Cultural assets	1.4.1. Green urban areas	1,8
	1.4.2. Sport and leisure facilities (including archaeological sites)	2,7
Agriculture	2.1.1. Non-irrigated arable land	2,4
	2.1.2. Permanently irrigated land	3,3
	2.1.3. Rice fields	2,6
	2.2.1. Vineyards	2,8
	2.2.1. Fruit trees and berry plantations	2,6
	2.2.1. Olive groves	2,3
	2.3.1. Pastures	2,1
	2.4.1. Annual crops associated with permanent crops	2,5
	2.4.2. Complex cultivation patterns	2,5
	2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	2,2
Forests	3.1.1. Broad-leaved forest	2,0
	3.1.2. Coniferous forest	1,9
	3.1.3. Mixed forest	1,7
Seminatural areas	3.2.1. Natural grassland	1,9
	3.2.2. Moors and heathland;	1,6
	3.2.3. Sclerophyllous vegetation	1,9
	3.2.4. Transitional woodland/shrub	1,6
	3.3.1. Beaches, dunes, sands	3,5
	3.3.2. Bare rock	2,1
	3.3.3. Sparsely vegetated areas	1,9
	3.3.4. Burnt areas	1,2
Wetlands	4.1.1. Inland marshes	1,8
	4.1.2. Peatbogs	1,6
	4.2.1. Salt marshes	2,7
	4.2.2. Salines	3,0
	4.2.3. Intertidal flats	2,4
Water bodies	5.1.1. Water courses	3,7
	5.1.2. Water bodies	3,3
	5.2.1. Coastal lagoons	2,9
	5.2.2. Estuaries	3,6

Table E.1 Erosion_Coastal assets and relative scores.

COASTAL FLOODING		
COASTAL ASSET	VARIABLE	FINAL VALUE
People and livelihoods	1.1.1. Continuous urban fabric	5,0
	1.1.2. Discontinuous urban fabric	4,1
Infrastructures	1.2.2 Road and rail networks and associated land	3,8
	1.2.3. Port areas	3,3
	1.2.4. Airports	2,5
	1.3.1. Mineral extraction sites	2,2
	1.3.2. Dump sites	3,3
	1.3.3. Construction sites	3,2
Industrial or commercial units	1.2.1. Industrial or commercial units	4,0
Socio-Cultural assets	1.4.1. Green urban areas	2,3
	1.4.2. Sport and leisure facilities (including archaeological sites)	2,5
Agriculture	2.1.1. Non-irrigated arable land	2,8
	2.1.2. Permanently irrigated land	3,3
	2.1.3. Rice fields	3,3
	2.2.1. Vineyards	2,8
	2.2.1. Fruit trees and berry plantations	2,6
	2.2.1. Olive groves	2,4
	2.3.1. Pastures	2,1
	2.4.1. Annual crops associated with permanent crops	2,3
	2.4.2. Complex cultivation patterns	2,4
	2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	2,3
Forests	3.1.1. Broad-leaved forest	2,1
	3.1.2. Coniferous forest	2,1
	3.1.3. Mixed forest	2,0
Seminatural areas	3.2.1. Natural grassland	2,0
	3.2.2. Moors and heathland;	1,7
	3.2.3. Sclerophyllous vegetation	2,5
	3.2.4. Transitional woodland/shrub	1,9
	3.3.1. Beaches, dunes, sands	2,9
	3.3.2. Bare rock	1,4
	3.3.3. Sparsely vegetated areas	1,8
	3.3.4. Burnt areas	2,2
Wetlands	4.1.1. Inland marshes	2,9
	4.1.2. Peatbogs	2,4
	4.2.1. Salt marshes	3,1
	4.2.2. Salines	3,3
	4.2.3. Intertidal flats	3,0
Water bodies	5.1.1. Water courses	3,9
	5.1.2. Water bodies	3,2
	5.2.1. Coastal lagoons	3,1
	5.2.2. Estuaries	3,6

Table E.2 Flooding_Variables of Exposure to Flooding and relative scores.

SALTWATER INTRUSION		
COASTAL ASSET	VARIABLE	FINAL VALUE
People and livelihoods	1.1.1. Continuous urban fabric	2,4
	1.1.2. Discontinuous urban fabric	2,2
Infrastructures	1.2.2 Road and rail networks and associated land	1,2
	1.2.3. Port areas	1,4
	1.2.4. Airports	1,2
	1.3.1. Mineral extraction sites	2,4
	1.3.2. Dump sites	1,3
	1.3.3. Construction sites	1,8
Industrial or commercial units	1.2.1. Industrial or commercial units	1,9
Socio-Cultural assets	1.4.1. Green urban areas	1,6
	1.4.2. Sport and leisure facilities (including archaeological sites)	2,2
Agriculture	2.1.1. Non-irrigated arable land	3,2
	2.1.2. Permanently irrigated land	3,7
	2.1.3. Rice fields	3,5
	2.2.1. Vineyards	3,5
	2.2.1. Fruit trees and berry plantations	3,5
	2.2.1. Olive groves	3,3
	2.3.1. Pastures	2,5
	2.4.1. Annual crops associated with permanent crops	2,9
	2.4.2. Complex cultivation patterns	2,8
	2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	2,7
Forests	3.1.1. Broad-leaved forest	2,2
	3.1.2. Coniferous forest	2,1
	3.1.3. Mixed forest	2,1
Seminatural areas	3.2.1. Natural grassland	1,5
	3.2.2. Moors and heathland;	1,6
	3.2.3. Sclerophyllous vegetation	2,1
	3.2.4. Transitional woodland/shrub	1,8
	3.3.1. Beaches, dunes, sands	1,6
	3.3.2. Bare rock	1,1
	3.3.3. Sparsely vegetated areas	1,5
	3.3.4. Burnt areas	1,7
Wetlands	4.1.1. Inland marshes	2,3
	4.1.2. Peatbogs	2,4
	4.2.1. Salt marshes	3,3
	4.2.2. Salines	3,2
	4.2.3. Intertidal flats	3,1
Water bodies	5.1.1. Water courses	2,3
	5.1.2. Water bodies	2,7
	5.2.1. Coastal lagoons	3,5
	5.2.2. Estuaries	3,0

Table E.3 SWI_Coastal assets scored and weighted.

MULTIPLE HAZARDS					
COASTAL ASSET	VARIABLE	EXP_{ERO}	EXP_{FLOOD}	EXP_{SWI}	**EXP_{MH}**
People and livelihoods	1.1.1. Continuous urban fabric	4,8	5,0	2,4	**4,07**
	1.1.2. Discontinuous urban fabric	3,7	4,1	2,2	**3,33**
Infrastructures	1.2.2 Road and rail networks and associated land	4,1	3,8	1,2	**3,03**
	1.2.3. Port areas	4,2	3,3	1,4	**2,97**
	1.2.4. Airports	3,6	2,5	1,2	**2,43**
	1.3.1. Mineral extraction sites	2,2	2,2	2,4	**2,27**
	1.3.2. Dump sites	2,5	3,3	1,3	**2,37**
	1.3.3. Construction sites	2,9	3,2	1,8	**2,63**
Industrial or commercial units	1.2.1. Industrial or commercial units	4,5	4,0	1,9	**3,47**
Socio-Cultural assets	1.4.1. Green urban areas	1,8	2,3	1,6	**1,90**
	1.4.2. Sport and leisure facilities (including archaeological sites)	2,7	2,5	2,2	**2,47**
Agriculture	2.1.1. Non-irrigated arable land	2,4	2,8	3,2	**2,80**
	2.1.2. Permanently irrigated land	3,3	3,3	3,7	**3,43**
	2.1.3. Rice fields	2,6	3,3	3,5	**3,13**
	2.2.1. Vineyards	2,8	2,8	3,5	**3,03**
	2.2.1. Fruit trees and berry plantations	2,6	2,6	3,5	**2,90**
	2.2.1. Olive groves	2,3	2,4	3,3	**2,67**
	2.3.1. Pastures	2,1	2,1	2,5	**2,23**
	2.4.1. Annual crops associated with permanent crops	2,5	2,3	2,9	**2,57**
	2.4.2. Complex cultivation patterns	2,5	2,4	2,8	**2,57**
	2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	2,2	2,3	2,7	**2,40**
Forests	3.1.1. Broad-leaved forest	2,0	2,1	2,2	**2,10**
	3.1.2. Coniferous forest	1,9	2,1	2,1	**2,03**
	3.1.3. Mixed forest	1,7	2,0	2,1	**1,93**
Seminatural areas	3.2.1. Natural grassland	1,9	2,0	1,5	**1,80**
	3.2.2. Moors and heathland;	1,6	1,7	1,6	**1,63**
	3.2.3. Sclerophyllous vegetation	1,9	2,5	2,1	**2,17**
	3.2.4. Transitional woodland/shrub	1,6	1,9	1,8	**1,77**
	3.3.1. Beaches, dunes, sands	3,5	2,9	1,6	**2,67**
	3.3.2. Bare rock	2,1	1,4	1,1	**1,53**
	3.3.3. Sparsely vegetated areas	1,9	1,8	1,5	**1,73**
	3.3.4. Burnt areas	1,2	2,2	1,7	**1,70**
Wetlands	4.1.1. Inland marshes	1,8	2,9	2,3	**2,33**
	4.1.2. Peatbogs	1,6	2,4	2,4	**2,13**
	4.2.1. Salt marshes	2,7	3,1	3,3	**3,03**
	4.2.2. Salines	3,0	3,3	3,2	**3,17**
	4.2.3. Intertidal flats	2,4	3,0	3,1	**2,83**
Water bodies	5.1.1. Water courses	3,7	3,9	2,3	**3,30**
	5.1.2. Water bodies	3,3	3,2	2,7	**3,07**
	5.2.1. Coastal lagoons	2,9	3,1	3,5	**3,17**
	5.2.2. Estuaries	3,6	3,6	3,0	**3,40**

Table E.4 Coastal assets exposed to multiple hazards and average scores.