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Assessment of coastal risks to climate change related impacts at the regional scale: The case of the Mediterranean region

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ABSTRACT

This paper presents a Coastal Risk Index (CRI-MED) developed to assess coastal risks and vulnerabilities associated with the physical and socio-economic impacts of climate change in all Mediterranean coastal zones. CRI-MED is a spatial risk index, which combines variables (multiple data layers) representing different aspects of risk in such a way that coastal areas of relatively higher risk emerge from the integration of the variables. It creates an interface between theoretical concepts of risk and the decision-making process relating to disaster risk reduction. Based on a GIS application, CRI-MED provides relative hazard, exposure, vulnerability and risk maps of the Mediterranean region that allow researchers and policy-makers to identify coastal areas most at risk from coastal erosion and coastal flooding, the so-called "hot-spots". Through the application of CRI-MED on 21 Mediterranean countries, coastal hot-spots are found to be predominantly located in the south-eastern Mediterranean region. Countries with the highest percentage of extremely high risk values are Syria (30.5%), Lebanon (22.1%), Egypt (20.7%), and Palestine (13.7%). The CRI-MED method is intended as a scientific tool which produces easily understandable outcomes, to support international organizations and national governments to enhance and mainstream decision-making based on information that is accessible and useful. The definition of coastal hot-spots aims to support the prioritization of policies and resources for adaptation and Integrated Coastal Zone Management (ICZM). In particular, the resulting risk maps enable identification of suitable and less suitable areas for urban settlements, infrastructures and economic activities.

1. Introduction

The Mediterranean region and in particular its coastal zones are severely affected by impacts of extreme climatic events (e.g. storm surges), coupled with human-induced pressures (e.g. uncontrolled building on coasts), resulting in growing vulnerability. Therefore, a compelling need emerges to understand how impacts to coastal zones in the Mediterranean region could evolve under the effects of climate change and to develop methodologies that can assess the resultant vulnerabilities and risks. Despite the increasing demand for consistent and robust scientific data for the region, there is currently no readily available source of information on current conditions as well as on future developments of the coastal zones for the Mediterranean countries [35]. Therefore, collecting and geo-referencing such data is a challenging task for researchers.

Moreover, there is a need for a regional index comparing risk across countries, including the identification of main vulnerabilities, which can be used by international organizations and national governments. This paper presents the development of a Coastal Risk Index methodology for risk assessment in the Mediterranean region (CRI-MED) and

Acronyms and abbreviations: AR5, IPCC Fifth Assessment Report; CCI, Climate Change Initiative; CCFVI, Coastal City Flood Vulnerability Index; CE, Coastal Exposure (sub-index); CH, Coastal Hazard (sub-index); CIRCE Project, Climate change and impact research: the Mediterranean environment; ClimVar & ICZM Project, Integration of climatic variability and change into national strategies to implement the ICZM protocol in the Mediterranean; CRI-MED, Coastal Risk Index for risk assessment in the Mediterranean region; CSI, Coastal Sub-Index; CV, Coastal Vulnerability (sub-index); CVI, Coastal Vulnerability Index; CVI-SLR, Coastal Vulnerability Index for Sea Level Rise; DEM, Digital Elevation Model; DESYCO, DEcision support SYstem for COastal climate change impact assessment; DIVA, Dynamic and Interactive Vulnerability Assessment; DRO, Droughts; EEA, European Environment Agency; EDU, Education level; ELE, Elevation; ICZM, Integrated Coastal Zone Management; IPCC, Intergovernmental Panel on Climate Change; ISCED, International Standard Classification of Education; GIS, Geographic Information System; GDP, Gross Domestic Product per capita; GEF, Global Environment Facility; LC, Land cover; LF, Landform; MEDSEA, Mediterranean Sea and Coast Foundation; Multi-scale CVI, Multi-scale Climate Vulnerability Index; P65, Population over 65; PDE, Population density; PGR, Population growth; ROU, Roughness; RVA, Regional Vulnerability Assessment; SRTM, Shuttle Radar Topography Mission; SLR, Sea Level Rise; SWH, Significant Wave Height; SWH95p, Significant Wave Height 95 percentile; TOUR, Tourist arrivals; UNEP/MAP, United Nations Environment Programme/Mediterranean Action Plan; W, Weight; WGII, IPCC Working Group II: Impacts, Adaptation and Vulnerability

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the results of its application. CRI-MED is a methodology for the integrated assessment of risk and vulnerability to the physical and socio-economic impacts of climate and non-climate driving forces to coastal zones. The CRI-MED method was applied regionally to measure risk, originally in eleven countries (Albania, Algeria, Bosnia and Herzegovina, Croatia, Egypt, Libya, Montenegro, Morocco, Palestine, Syria and Tunisia) of the ClimVar & ICZM Project and later on extended to the following countries of the Mediterranean Sea (France, Greece, Israel, Italy, Lebanon, Malta, Slovenia, Spain, and Turkey). The present research is part of the ClimVar & ICZM Project "Integration of climatic variability and change into national strategies to implement the Integrated Coastal Zone Management (ICZM) Protocol in the Mediterranean" implemented by the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP) and aimed at assessing the risks of climate change impacts on coastal ecosystems and local communities in the Mediterranean.

1.1. Overview of major climate-related changes and vulnerabilities across costal zones in the Mediterranean

The research focuses on risks associated to Sea Level Rise (SLR), storms and droughts as major climate-related changes affecting Mediterranean coastal zones. Physical changes in the Mediterranean climate have been widely observed and such trends are projected to continue in the future. A rise of 7–12 cm in the overall level of the Mediterranean Sea compared to the past decades is projected by 2050 [21], with larger SLR occurring on Eastern and Southern Mediterranean coasts. Climate change hazards are coupled with existing socio-economic processes associated with growing bio-geographical vulnerability and exposure in coastal areas of the Mediterranean region. SLR and storm-related floods will make low-lying zones and coastal activities increasingly vulnerable to submersion and beaches vulnerable to erosion [57]. Losses of coastal and marine habitats and ecosystems are also largely implied [8]. Scientists and practitioners advise that the identification of adaptation actions be made ad hoc, based on the assessment of local conditions of impacts and risk/vulnerability and the analysis of costs and benefits of options to adapt. SLR is an issue of concern with some regions of the Mediterranean basin showing increasing trends of more than 0.6 cm/year, and others showing decreases of more than 0.4 cm/year in absolute sea level from 1992 to 2013 as observed by satellites, against a global mean of about 0.3 cm/year over the last two decades. As for projections of future changes in the level of the Mediterranean Sea in the first decades of the 21st century, the Intergovernmental Panel on Climate Change (IPCC) reports projections of SLR in the range of 10–30 cm by 2050 and of 10–90 cm by 2100, with major impacts on the southern Mediterranean region [30]. The simulations conducted by the project "Climate change and impact research: the Mediterranean environment" (CIRCE) [41] based on the IPCC A1B emission scenario describes a world of very rapid economic growth, with a rapid introduction of new and more efficient technologies balanced across all energy sources [32]. The simulations confirmed an increase in the overall level of the Mediterranean Sea ranging between around 7–12 cm in the period 2021–2050 [21]. The projections of extreme storm surges for the Mediterranean basin are not univocal. According to existing studies, climate change presents a small effect on marine storms and "suggest weaker marine storms in future scenarios than in the present climate" [21]. Some speak of a decrease in the frequency of storms towards the eastern part of the Mediterranean [11], but also an increase in storminess for parts of the Adriatic and Aegean Sea [23]. A study by Marcos et al. [36] projected a reduction in both the number and frequency of storm surge events during the 21st century in the Mediterranean basin. More recently, Conte and Lionello [12] investigated the effects of climate change on storms integrating studies carried out in several Mediterranean coastal zones based on a new set of climate simulations and datasets produced in the CIRCE project. Their analysis confirmed that "storm surges extremes are little affected by climate change with changes within the ± 5% range" [12]. Nevertheless, marine storms and related storm surges can represent a major issue for the assessment of coastal risk. The uncertainty in the likelihood of disastrous events is one of the main issues for risk assessment and managing hazards related to future marine storms [21]. Recent research [13] highlighted the role of climate change in contributing to observed drying trends. According to Cook et al. [13] recent droughts are mainly centered in the western Mediterranean, Greece and in the Middle East. Droughts are expected to intensify in the Mediterranean [31] representing a major concern for water scarcity. Droughts coupled with SLR and storms represent a relevant issue for risk assessment of coastal erosion [6,7].

1.2. Defining and measuring risk

According to the IPCC [29] definition, Risk is characterized as "the potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain". At the same time, Risk is often represented as "the probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur" [29]. Combining these two definitions, Risk in this paper is considered as a function of hazards, vulnerability and exposure, as described in Fig. 1 [29]. Definitions of risk components are presented in Table 1.

Coastal Risk generated from impacts of extremes climate events can be considered at various spatial scales. Since adaptation and ICZM policies are undertaken by organizations operating at different levels, assessment methods must address coastal risk at appropriate scales [38], involving different indicators, data availability and multiple types of data. There is no one-size-fits-all method to measure coastal risk and vulnerability, and the utility of the assessment methods varies with scale [48].

1.3. Analysis of existing risk assessment tools

As preliminary methodological step, a background analysis on the state of research into existing risk assessment tools was conducted. It aimed to identify the most appropriate basis to develop the proposed methodology for assessing climate and non-climate risks in the Mediterranean coastal zones. The analysis of tools focused on those originated in and designed specifically for the Mediterranean region, as well as those assessing risks and vulnerabilities relevant to the Mediterranean region. Tools designed for a much broader range of places and sectors were also included to draw on best-practice risk and vulnerability assessment processes from around the world. This background analysis was based on the work done by Satta [49]. Tools selected for this analysis cover four main categories: 1) Methods based on dynamic computer models; 2) Visualization tools; 3) Index/Indicators-based methods; 4) GIS-based decision-support tools. In order to assess the tools appropriately, evaluation criteria that reflect the needs of the

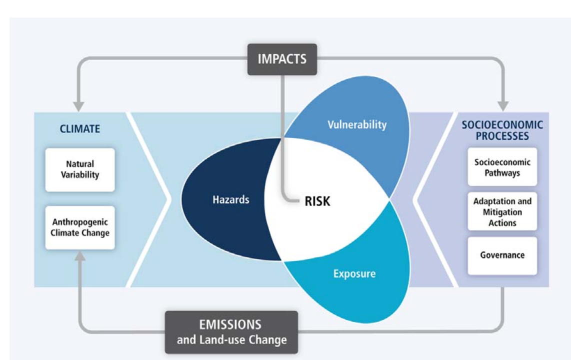

Fig. 1. Risk as a function of hazards, vulnerability and exposure (source: IPCC [29]).