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Review

Indicator-based assessment of climate-change impacts on coasts: A review of concepts, methodological approaches and vulnerability indices

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ABSTRACT

Increasing human pressures on coastlines and associated threats posed by sea-level rise have stimulated development of a range of different concepts and methodological approaches to assess coastal vulnerability. The first section of this paper summarizes the concepts associated with vulnerability, natural hazards and climate change. The most widely adopted analytical approaches to vulnerability assessment are described, including spatial scales, the need for hybrid approaches comprising both biophysical and social dimensions of vulnerability, and the gradual incorporation of resilience aspects into such methodologies. In particular, the development and application of vulnerability indices is examined, based on a review of more than 50 studies that applied such indices across a range of hazards. The analytical procedures, proposed typologies, and most commonly selected variables are discussed. This overview demonstrates the breadth of vulnerability studies. This leads inevitably to lack of standardization of concepts and assumptions, which results in limited comparability between outputs for coasts from different areas. However, the widespread demand for vulnerability assessment as a component of decision-making in integrated management of the coast justifies pursuing indicator-based vulnerability assessments. In some cases these will explicitly adopt a consistent methodology that enables comparison between sites, whereas alternatively, metrics may be developed that are designed around particular system components and the site-specific functions for which they are valued.

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Contents

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1. Introduction

Sea-level rise associated with climate change is globally considered to be a serious threat, especially for low-lying and densely populated areas (Bindoff et al., 2007; Bigano et al., 2008). The coast is one of the most vulnerable areas to potential impacts of climate change, particularly because of anticipated future sea-level rise (Wong et al., 2014). The coastal zone is an important natural resource system, which provides space, as well as living and non-living resources for human activities, and has since the early days of civilisation. Past fluctuations of sea level have been significant factors in the evolution of cultures on a historical time scale and civilisations have founded or expanded as relative sea levels have shifted. The coastal zone is currently a focal point in many national economies with a large number of social and economic activities concentrated near the shoreline.

The importance of the coastal zone will further intensify in future, due to the ever-increasing number of people who live there. Adger et al. (2005) indicate that 1.2 billion people, which accounts for 23% of the world's population, now live within 100 km of the coast, and about 50% of the world's population are likely to do so by 2030 (Neumann et al., 2015). While living near the coast is advantageous, it also exposes the inhabitants to an increasing number of detrimental impacts which are exacerbated by climate change, with elevated water levels becoming more frequent and severe due to intensively aggregated human activities. There is a need, therefore, to assess coastal vulnerability to impacts of climate change. Methodologies for assessing vulnerability, as widely suggested by the Intergovernmental Panel on Climate Change (IPCC) since their initial common methodology report in 1991 (IPCC, 1991), need to consider both biophysical and social aspects, and their mutual interaction, to adequately set up relevant adaptation policies for sustainable development. Such methodologies have been widely used both in academic research (e.g. Abuodha and Woodroffe, 2006; Sudha Rani et al., 2015) as well as for management purposes (e.g. Pendleton et al., 2005).

In this paper a broad range of literature on vulnerability to hazards is reviewed. Specifically, more than fifty studies that applied vulnerability indices for a range of hazards were assessed to identify fundamental concepts that could be applied to coastal risk analysis. The most widely adopted analytical approaches are described, and their integration into coastal vulnerability indices is summarized. This overview demonstrates the breadth of vulnerability studies and the lack of standardization of concepts, scales, simplifications and selected parameters adopted in the development of indices for identification of vulnerable areas.

2. The conceptualization of vulnerability

The initial scientific use of "*vulnerability*" has its roots in geography and natural hazards research, but now this term is a central concept in a variety of research contexts related to natural impacts, such as salinity incursion, drought, bushfire, flooding and inundation, erosion and sedimentation, as well as social effects, such as poverty, famine, and landuse change (Füssel, 2007; Toan, 2014; Li et al., 2015). Adger (1999) and O'Brien and Leichenko (2001) indicate that vulnerability is not an outcome, but rather a state or condition of being, and a very dynamic one at that, moderated by existing inequities in resource distribution and access, the control individuals can exert over choices and opportunities, and historical patterns of social domination and marginalisation.

2.1. Defining vulnerability

White (1974) indicated that "v*ulnerability is the degree to which a system, sub-system, or component is likely to experience harm due to exposure to a hazard, either a perturbation or stress*". Later, Timmermann (1981) hypothesized that "*vulnerability is a term of such broad use as to be almost useless for careful description at the present, except as a rhetorical indicator of areas of greatest concern*". Liverman (1990) noted that vulnerability *"has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk"*. Other concepts such as exposure, sensitivity, coping capacity, criticality, and robustness could also be added to this list (Füssel, 2007; Wolters and Kuenzer, 2015). It is apparent that there is no single optimal definition of vulnerability that would fit all assessment contexts. It is important to note that the diversity of definitions can be considered as a primary consequence of the term "*vulnerability*" being used in different policy contexts, referring to different systems exposed to different impacts.

Accordingly several authors have emphasized that the term "*vulnerability*" can only be considered meaningfully with reference to a specific vulnerable situation (Brooks, 2003; Luers et al., 2003; Downing and Patwardhan, 2004; Metzger et al., 2005; Füssel, 2007; Hinkel and Klein, 2007). Fundamental dimensions of a *vulnerable situation* include: the *system* that is subject to analysis, such as an integrated human-environment system, a population group, an economic sector, a geographical region, or a natural system; the valued *attributes of concern*, which might include for example human lives and health, the existence, income and cultural identity of a community, and the biodiversity, carbon sequestration potential and timber productivity of a forest ecosystem; the *hazard*, which refers to a potentially damaging influence on the system; and a *temporal reference*, which refers to the point in time or time period of interest, (e.g., current vs. future vs. dynamic) (Füssel, 2007).

A clear description of the vulnerable situation is an important first step to avoid confusion concerning vulnerability. A clear description is important as different classifications of vulnerability by scientists from different disciplines or with varying perceptions produces different interpretations of the term "*vulnerability*".

2.2. Biophysical and socio-economic aspects of vulnerability

Several researchers distinguish biophysical or natural vulnerability from social or socio-economic vulnerability, (e.g., biophysical vs. social), even though there is little agreement on the meaning of these terms (Cutter, 1996; Adger, 1999; Klein and Nicholls, 1999; Mclaughlin et al., 2002; Brooks, 2003; Cutter et al., 2003; Meur-Férec et al., 2008; Mclaughlin and Cooper, 2010; Soares et al., 2012; Sudha Rani et al., 2015). Other classifications have been proposed; for example, Moss et al. (2001) suggest including physical-environmental, socio-economic, and external assistance dimensions; the United Nations (2004) suggest including physical, economic, social, and environmental factors; and Fekete et al.

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