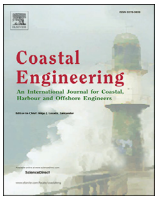
Coastal Engineering xxx (2017) 1–15

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng



Selecting coastal hotspots to storm impacts at the regional scale: a Coastal Risk Assessment Framework

C. Viavattene [a,*], J.A. Jiménez [b], O. Ferreira [c], S. Priest [a], D. Owen [a], R. McCall [d]

[a] Flood Hazard Research Centre, Middlesex University, London, UK
[b] Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya·BarcelonaTech, c/Jordi Girona 1-3, Campus Nord ed D1, 08034 Barcelona, Spain
[c] CIMA/FCT, University of Algarve, Faro, Portugal
[d] Dept. ZKS, Deltares, Delft, The Netherlands

ARTICLE INFO

Keywords:
Regional assessment
Response approach
Systemic impact
Multi-criteria analysis

ABSTRACT

Managing coastal risk at the regional scale requires a prioritization of resources along the shoreline. A transparent and rigorous risk assessment should inform managers and stakeholders in their choices. This requires advances in modelling assessment (e.g., consideration of source and pathway conditions to define the probability of occurrence, nonlinear dynamics of the physical processes, better recognition of systemic impacts and non-economic losses) and open-source tools facilitating stakeholders' engagement in the process.

This paper discusses how the Coastal Risk Assessment Framework (CRAF) has been developed as part of the Resilience Increasing Strategies for Coasts Toolkit (RISC-KIT). The framework provides two levels of analysis. A coastal index approach is first recommended to narrow down the risk analysis to a reduced number of sectors which are subsequently geographically grouped into potential hotspots. For the second level of analysis an integrated modelling approach improves the regional risk assessment of the identified hotspots by increasing the spatial resolution of the hazard modelling by using innovative process-based multi-hazard models, by including generic vulnerability indicators in the impact assessment, and by calculating regional systemic impact indicators. A multi-criteria analysis of these indicators is performed to rank the hotspots and support the stakeholders in their selection.

The CRAF has been applied and validated on ten European case studies with only small deviation to areas already recognised as high risk. The flexibility of the framework is essential to adapt the assessment to the specific region characteristics. The involvement of stakeholders is crucial not only to select the hotpots and validate the results, but also to support the collection of information and the valuation of assets at risk. As such, the CRAF permits a comprehensive and systemic risk analysis of the regional coast in order to identify and to select higher risk areas. Yet efforts still need to be amplified in the data collection process, in particular for socio-economic and environmental impacts.

1. Introduction

Increasing coastal threats, exposure and risk pose a problem for the sustainable development and management of our coasts (Hallegatte et al., 2013; IPCC, 2015). Firstly it requires a re-evaluation of the current standard of protection of areas behind which exposure has increased. Secondly it necessitates the recognition of newly exposed and non-defended areas resulting from the expansion of built-up areas (Neumann et al., 2015). Thirdly it requires an assessment of potential indirect and systemic impacts to better measure the resilience of coastal communities (UNISDR, 2015). As such, there is an increased demand for action which consequently requires a prioritization in the choice of actions and funding to be allocated for mitigating the risk. Scarcity in resources imposes the need for a transparent and rigorous risk assessment process, including various scales of governance (Driessen et al., 2016; Alexander et al., 2017). A succession of tools and approaches have been developed to support decision-making processes with the objective of better integration of various threats and impacts, better stakeholder involvement as well as a wider application of those tools through the provision of open-source methodologies and by increasing ease of use (Zanuttigh et al., 2014; Torresan et al., 2016a; Vafeidis et al., 2008). The RISC-KIT tool-kit (van Dongeren et al., 2014) sustains this transfer of

---

* Corresponding author. Middlesex University, The Burroughs, Hendon, London, NW4 4BT, UK.
E-mail address: c.viavattene@mdx.ac.uk (C. Viavattene).

http://dx.doi.org/10.1016/j.coastaleng.2017.09.002
Received 28 January 2017; Received in revised form 30 August 2017; Accepted 7 September 2017

Please cite this article in press as: Viavattene, C., et al., Selecting coastal hotspots to storm impacts at the regional scale: a Coastal Risk Assessment Framework, Coastal Engineering (2017), http://dx.doi.org/10.1016/j.coastaleng.2017.09.002

knowledge within the research and development, the engineering, and the coastal management community by providing a series of tools to better understand coastal risk, to measure that risk at various coastal scales and to assess the effectiveness and potential of Disaster Risk Reduction (DRR) measures.

The RISC-KIT project acknowledges that the high demand in terms of data, time and resources required for a detailed risk-assessment is prohibitive for a comprehensive and detailed risk assessment of an entire coastal region. Such an assessment requires high-resolution (e.g., 10 m scale) predictions for multiple (thousands of) scenarios using computationally-intensive high-fidelity modelling techniques, as well as detailed information on receptors, vulnerability and disaster reduction measures, and is therefore impractical for application at the regional or national (100–1000 km) scale.

Within this context, the RISC-KIT project provides a comprehensive and systematic methodology, called the Coastal Risk Assessment Framework (CRAF), in which a first assessment of impact and risk is carried out at the regional scale to identify so-called hotspots, defined as specific locations with the highest risk (on the scale of 1–10 km). A further detailed analysis of coastal hazards and impacts, as well as the effectiveness of DRR measures can subsequently be carried out at individual hotspots using the RISC-KIT hotspot tool (Bogaard et al., submitted).

This present paper presents the two-step methodological approach adopted in the framework. The overall CRAF is first introduced in section 2 outlining differences between the two phases of the approach. The large-scale coastal index (CRAF Phase 1) approach is then detailed in section 3 with explanations of the index calculation, methodological choices and of the assessment process for probability, hazards and exposure elements of the index. Section 4 focuses on the CRAF Phase 2 explaining the hazard computation, the impact assessment model and the multi-criteria analysis used to perform the hotspot selection. This contribution presents and discusses the CRAF methodology and some of the lessons learned in section 5. However, this paper also complements six other papers in this special issue, with some of them applying this methodology. In particular, the lessons learned from existing CRAF applications are further discussed in the “Storm-induced risk assessment: evaluation of tool application” paper (Ferreira et al., 2017). For a detailed discussion and validation of the CRAF application on specific case studies the reader is also directed to papers detailing its application on two Italian coasts (Emilia-Romagna coast and Liguria coast (Armaroli and Duo, 2017; De Angeli et al., 2017)), on the North Norfolk coast in England (Christie et al., 2017), on the coast of Kristianstad in Sweden (Barquet et al., 2017) and on the Catalonian coast in Spain (Jiménez et al., 2017).

2. Coastal risk assessment framework

Existing approaches have been developed for supporting the coastal vulnerability analysis along the coast at different scales, amongst them are: the model DIVA (Dynamic Interactive Vulnerability Assessment) (Hinkel and Klein, 2009); the RVA method (Regional Vulnerability Assessment) (Torresan et al., 2012); CERA (Coastal Erosion Risk Assessment) (Narra et al., 2017); or the CRI-LS index (Multi-scale Coastal Risk Index for Local Scale) (Satta et al., 2016). GIS index-based approaches dominate (Gornitz, 1990) and principally consist of combining different standardised indicators which are derived from various sources of information. These approaches have their advantages as they are user-friendly; do not require high level of expertise; can use various source of data and integrate uncertainty in the assessment by performing relative comparisons (Satta et al., 2016; Balica et al., 2012). It must be noted, here, that the number of indicators included in these indices has significantly increased over the years. Whereas Gornitz (1990) (Gornitz, 1990) only included hazard indicators (i.e. geomorphology, slope, sea level change, erosion, tidal range, wave height), new indices include dozens of them (Torresan et al., 2012; Narra et al., 2017; Satta et al., 2016; Balica et al., 2012). The increase in the number of indicators is explained by the needs of multi-hazard assessment (e.g. inclusion of drought, surge, and cyclone), the inclusion of socio-economic and environmental indicators (e.g. land use, population, cultural heritage) and resilience/resistance indicators (e.g. presence of shelters, defences, and awareness). The better consideration of a full impact assessment benefits the analysis. However, the combination of multiple indicators using simple additive or multiplicative operations may be questioned in particular if there is some degree of overlap between indicators (Balica et al., 2012). It also reduces the simplicity of the index and, as such, it requires a better understanding by the users of the indicators (Torresan et al., 2012). In particular, levelling everything to an “average” value may not be representative with a potentially high impact to a certain indicator being minimised by the lower values of other impacts. Such levelling may then lead to a false sense of low impact overall. A multi-hazard indicator also poses a problem of double-counting or miscounting. As such, in the case of flooding and erosion the number of buildings exposed to these hazards differs. For assets exposed to both hazards there is a question whether a building which suffers from flooding and then also collapses due to erosion should be scored higher than a building collapsing just by erosion; as the additional losses caused by the flooding become irrelevant. Another limitation of the existing approaches is the lack of assessment of indirect and systemic impacts. The vulnerability of the critical infrastructures (road network, utilities) and the consequences for the population not exposed to the hazard but dependant of these services is often not considered. Yet a comprehensive understanding and representation of the coastal system is required (Narayan et al., 2012).

An alternative existing approach is to use methods integrating processed-based morphological models, inundation models and flood loss assessment models in order to assess the impacts and the risk following the source-pathway-receptor-consequence approach (Schanze et al., 2006). Processed-based morphological and inundation models permit the generation of flood and erosion maps, which can be used as an input for flood loss assessment models. Flood loss assessment models have mainly been developed to assess fluvial flooding impacts (Meyer et al., 2013; Jongman et al., 2012; Gerl et al., 2016); e.g., HAZUS in the USA, LATIS in Belgium, HIS-SSM in Netherlands, FLEMO in Germany, the MCM in England and Wales. DESYCO and THESEUS are examples of recent GIS integrated coastal models using flood loss assessment models (Zanuttigh et al., 2014; Torresan et al., 2016b). They are deterministic models combining vulnerability functions, receptor maps and hazard maps to estimate the consequential losses. The vulnerability functions are often expressed as depth-damage curves and vary from one country to another for a better representation of the characteristics of the receptors but large uncertainty remains in these functions (Jongman et al., 2012; Penning-Rowsell et al., 2013). The resulting direct impacts can then be input into additional models, such as input-output models, computable general equilibrium models, network analysis or object-orientated models to better assess indirect and cascading impacts (Carrera et al., 2015; Demirel et al., 2015; Serre, 2016; Ouyang and Dueñas-Osorio, 2014; Eusgeld et al., 2009).

This paper recognises the advantages of using both the GIS index-based and integrated modelling approaches to support a risk assessment and the selection of hotspots in collaboration with stakeholders at the regional scale. Such arrangement permits bridging scientists and practitioners' perspectives. From a research standpoint advancement are expected in assessment modelling including; deriving the coastal hazard from the external boundary conditions by better recognizing the nonlinear dynamics of the physical processes, associating source and pathways in the probability of occurrences, improving the consideration of indirect impacts, involving stakeholders and supporting an integrated assessment. From a practical perspective it is essential to develop a tool that could be used with confidence. The inherent question in developing such a framework is the level of simplicity that could be achieved. Simplicity is necessitated as data, skills and resources are limited.