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A framework to include the (inter)dependencies of Disaster Risk Reduction measures in coastal risk assessment

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ABSTRACT

Effective coastal risk management often involves the selection and appraisal of Disaster Risk Reduction (DRR) measures. Such measures, however, are rarely implemented in isolation and their (inter)dependencies need to be considered to assess the overall contribution to risk reduction. This paper presents a framework that utilises a pathway-based approach to consider such (inter)dependencies. The framework identifies measures that have the potential to directly influence risk reduction (primary measures) at the individual/household level and how these relate to the implementation of other measures (non-primary). These two types of measures are linked using intermediate pathway factors, which aggregate to the effective uptake and/or operation of primary measure(s) and subsequently represent the direct influence on risk reduction when included in a risk assessment.

The approach is demonstrated utilising two coastal risk examples. The case of Varna Bay, Bulgaria highlights a pathway, which explores how developing a coastal Early Warning System (EWS), can enable assets to be moved and saved prior to an event. The Praia de Faro, Portuguese application provides an example of how local risk awareness meetings can support the uptake of property raising to protect against erosion. Past experience, poor trust in authorities, house type/feasibility, transient population and strong community networks are identified as key influencing variables across both cases.

The process of considering the (inter)dependencies between measures has potential to lead to improved decision-making and strategy building. The framework developed is flexible in nature and can be applied in many different situations; however, it is one step towards accounting for these (inter)dependencies at the individual/household level. Ex-ante or ex-post survey data, expert judgement and literature have been used to estimate these factors. However, in many cases this good quality data is not available, and is something that national level monitoring strategies, along with the research community, must address.

1. Introduction

Recent and historic low-frequency, high-impact coastal events have demonstrated extensive social and economic impacts on large cities and countries, such as Xynthia (impacting France in 2010), North Sea storm (impacting Netherlands and Belgium, 1953), and Superstorm Sandy (impacting the north-eastern USA, 2012). Coastal communities exposed to such water-related hazards need to both adapt and prepare for larger disasters than being experienced today (Hallegatte et al., 2013). Coherently, recently adopted global policies all highlight the need to develop and monitor, strategies and plans, that reduce disaster risk, and build adaptive capacity to climate change, (e.g. Sustainable Development Goals (United Nations, 2015), Sendai Framework for Disaster Risk Reduction (DRR) (UNISDR, 2015), Paris Agreement on Climate Change (UNFCCC, 2015) and New Urban Agenda (UN-Habitat, 2016)). Furthermore, at a regional level, European member states are obliged to define and update integrated flood and coastal risk management plans and address climate change, see the European Union Floods Directive (European Union, 2007), and European Union Strategy on Climate Adaptation (European Commission, 2013). Such strategies or plans often

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comprise a number of different "measures", as they are known within the flood risk and DRR community (UNISDR, 2015; European Union, 2007; Kreibich et al., 2015; Schanze et al., 2008), or "options" which is more commonly used in the Climate Change Adaptation (CCA) community (Lim et al., 2004; De Bruin et al., 2009; Klein et al., 2001; Hallegatte, 2009). In light of the Sendai Framework for DRR, and the acknowledgement that CCA is a component of DRR (Kelman et al., 2015), the overarching term "DRR measures" is used for the purpose of this paper.

There are various categorisations of such measures; structural vs. non-structural (Parker et al., 2007a; Hutter et al., 2008; Penning-Rowsell and Fordham, 1994), hard vs. soft measures (Hall and Solomatine, 2008), measures vs. instruments (Olfert and Schanze, 2005). Some categories of measures identify the direct influence on hazard (e.g. structural measures such as coastal flood defences and beach nourishment), vulnerability (e.g. non-structural measures such as property level protection) and others identify the indirect effects that aim to influence behaviour (e.g. instruments such as early warning systems (EWS), preparedness planning and insurance). However, these existing categorisations of measures lack consideration of the (inter)dependencies between different measures, for instance needing an effective risk awareness programme to incentivise property level protection or a EWS to facilitate successful and timely movement of assets. These (inter)dependencies are fundamental to the evaluation of any potential impact reduction.

There is consensus that investing in the economic and social benefits of such DRR measures has the potential to outweigh the costs (De Bruin et al., 2009; Rogers and Tsirkunov, 2010; Penning-Rowsell et al., 2005; Pappenberger et al., 2015). The evaluation of individual measures, and combinations thereof, supports a rational comparison between measures against a baseline situation (Penning-Rowsell et al., 2013). A comparison between measures or strategies is often made using Multi-Criteria Analysis and/or Cost-Benefit Analysis (De Bruin et al., 2009; Penning-Rowsell et al., 2005; Hajkowicz and Collins, 2007; Van Ierland et al., 2013) which can be supported with modelled input from risk assessments. Risk assessments have mainly focused on modelling direct-tangible economic damages (Jongman et al., 2012; Merz Kreibich et al., 2004) using depth-damage curves (Messner and Meyer, 2006; Meyer et al., 2013) or empirical overall damage reduction factors (Parker et al., 2007a; Thurston et al., 2008). Assessing the benefits of those DRR measures that affect the hazard directly (e.g. raising a dike) is relatively straightforward as modelling can be undertaken to calculate the modified flood depth. DRR measures at an individual scale (e.g. property-level resistance or resilience measures, raising or evacuation of stock or property contents) can also be represented within risk assessment through the modification of depth-damage curves (Thurston et al., 2008; Viavattene et al., 2015).

DRR measures such as coastal EWS or awareness raising programmes, which on their own, may not directly influence any risk reduction, may be fundamental to the effectiveness of other measures that directly influence risk reduction and need to be evaluated differently. These connections and dependencies between the DRR measures are important to consider when evaluating measures and devising strategies. Methodologies have been proposed that evaluate the benefits of EWS that utilise different reduction factors which consider that 100% of the population cannot be expected to receive, have the ability to, and are willing to effectively respond to a warning and take appropriate actions (Parker et al., 2007b; Priest et al., 2011; Molinari and Handmer, 2011; Carsell et al., 2004) and others estimate the Uptake (UP) and Operator (OP) factors of individual measures (Parker et al., 2008; Clarke et al., 2015; Clarke, 2015). Although these do explore connections between different measures they do not address the connections with other measures like emergency planning, awareness raising, and financial and legal instruments, providing an opportunity for further research. Indices are often used to quantify the social characteristics of the population, (e.g. the Social Flood Vulnerability Index (SFVI) in the UK (Tapsell et al., 2002), and in the United States (Cutter et al., 2008; Flanagan et al., 2011; Rygel et al., 2006)) and many of the factors in such indices can influence the uptake and operation of measures. Understanding the threat and coping appraisal and its impact on behavioural response (Bubeck et al., 2013) can offer further insights into the uptake and operation of measures. This previous research and methods can be built upon and utilised to understand and evaluate the risk reduction of pathways of interdependent measures that accounts for social and behavioural factors.

The research presented here aims to provide an innovative framework to incorporate interdependent DRR measures in coastal risk assessments utilising a pathway-based approach. The framework involves selecting DRR measures that directly and indirectly influence risk reduction at the household/individual level, defining the intermediate pathway factors and associated influencing variables between these measures, and quantifying these factors using the best available data to estimate the appropriate UP and OP factors. The output can be used to estimate the risk reduction using the most appropriate risk assessment method. Adopting this framework permits the consideration of a broader range of measures within risk assessment and recognizes the (inter)dependencies between DRR measures in combination. Firstly, the framework and how to use it are described, and example applications from the RISCKIT project case studies in Varna, Bulgaria and Praia de Faro, Portugal are presented. Finally, further discussion of the benefits and limitations of the framework are considered.

2. Framework development

2.1. Identifying interdependent DRR measures

Any flood risk or DRR plan aims to reduce the probability of hazards and/or their potential consequences (UNISDR, 2015; European Union, 2007) by implementing a prioritized set of tailored measures. Such a set of measures can be termed a portfolio (Hall and Solomatine, 2008; Penning-Rowsell et al., 2014) or alternative strategies (Vis et al., 2003). As highlighted previously, various contested categorisations of measures have been proposed related to the way in which they reduce risk (structural vs. non-structural), whether they are engineering based or otherwise (hard vs. soft) or the timing of their implementation (pre, during, post event). These characterisations, however, generally lack emphasis on the required connections between different measures necessary for effective implementation. Although Olfert and Schanze (2007) touch upon connection in their definition of instruments as "indirectly shaping scope for action" the specific dependencies are not identified. It is critical to make the links clearer between measures that may have a necessary general effect (e.g. awareness raising campaigns) and the implementation of a measure that directly reduces the hazard, exposure or vulnerability of a receptor. Omitting consideration of these (inter)dependencies when scoping, assessing or selecting a DRR measure may lead to an underestimation of the difficulties of implementation and/or sub-optimal strategies being selected. Building on the approaches by Priest et al. (2011). and Clarke et al. (2015) an innovative framework (Fig. 1), has been developed to further highlight the (inter)dependencies between multiple measures, along pathways through which they can be included when assessing their potential for risk reduction.

In this framework, although DRR measures will include all measures in the categorisations as outlined above, it distinguishes between *primary* measures and *non-primary* measures. *Primary measures* will directly influence risk reduction by modifying the vulnerability (e.g. by making a property less susceptible to damage; such as property level resilience measures) or the exposure of receptors (such as the evacuation of people or property out of the risk zone prior to an event). Importantly, primary measures are those where it is possible to make a direct link to risk reduction (e.g. damage assessment using depth-damage curves). These primary measures have been further grouped into active and passive preparedness measures, which is a first critical link to their dependency on other non-primary measures. Active preparedness measures require action before or during an event and as such may be dependent on the receipt of an early warning or actions of others (e.g. an evacuation instruction). These have been further divided into those that require