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FROM THEORY TO PRACTICE: CAN WE REALLY VALUE COASTAL FLOOD IMPACTS?

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ABSTRACT: Extremes events in combination with the increasing population on coast, future sea level rise and the deterioration of coastal defences can lead to catastrophic consequences for the coastal communities and their activities. The current paper describes the methodologies used to develop a set of coastal vulnerability indicators for receptors exposed in different European sites. A comprehensive and meaningful understanding of the vulnerability of the coastal system can only be achieved through a holistic analysis of various components of vulnerability. Vulnerability data has primarily been collected from existing European and National datasets supplemented by an exhaustive literature review. Whereas methods for assessing direct costs to the built environment have been developed in most parts of Europe as a mean of producing cost-benefits assessment of flood risk management project, assessing the potential impacts on the population and the environment remains rather limited. Much more difficult to evaluate is the dynamic response of the economic, environmental and social systems to this shock so that the resilience of these systems to external perturbations can be determined. This evaluation remains nevertheless essential for understanding the sustainability of coastal system in the face of extreme threats. Yet the availability of data for the different vulnerability components is variable. Significant issues remain in terms of data collection and availability to enable validation and to reduce the uncertainty associated with their assessment. Therefore it is often necessary to either use an averaged vulnerability indicator or to transfer a specific one from one region to another.

Key Words: Coastal flooding, impact assessment, vulnerability, systemic, sustainable development

Recent events (Katrina, Sandy, Haiyan, Xynthia, Cleopatra) have highlighted the increase of threats to the coastal system. Extremes events in combination with the increasing population on coast, future sea level rise and the deterioration of coastal defences can lead to catastrophic consequences for the coastal communities and their activities. This increase in risk along coasts requires a re-evaluation of coastal disaster risk reduction strategies and a new mix of prevention (e.g. dike protection), mitigation (e.g. limiting construction in flood-prone areas), preparedness (e.g. Early warning systems) and recovery measures (e.g. relief funds, insurance).

The Resilience-Increasing Strategies for Coasts - toolKIT (RISC-KIT) FP7 EU project (2013-2017) aims at producing a set of three innovative and EU-coherent open-source and open-access methods, tools and management approaches (the RISCKIT) in support of coastal managers,(emergency) decision-makers and policy makers (Figure 1). The CRAF is a Coastal Assessment Framework to assess coastal areas at regional case and to identify hotspots for more detailed assessment. The EWS is an Early Warning System providing real-time forecasts and early-warnings for the hotspots. It is combined with a Decision Support System assessing potential impacts with and without Disaster Risk Reduction measures. The combined DSS will be applied in dual mode: as a forecast and warning system and as a consistent ex-ante planning tool (Van Dongeren et al., 2013). The objective of the RISC-KIT project is has objective to demonstrate the robustness and applicability of the CRAF and EWS/DSS tools on case study sites on the coasts of all EU regional seas with diverse geomorphic settings (open coasts, lagoons, salt marshes, deltas and estuaries), land use (industrial infrastructures, coastal towns, marinas, tourist areas, natural parks and cultural heritage), forcing (tides, surges, waves), hazard types (erosion, overtopping, coastal rain-driven flash floods) and socio-economic, cultural and environmental characteristics. To do so, one output of the project is the development of a vulnerability indicator library to assess the impacts for each site with the CRAF and the EWS/DSS. The current paper introduces first the framework on analysis used to better assess potential coastal impacts and how it drives the development of the vulnerability library. Then the paper describes which models are used to develop this set of coastal vulnerability indicators for receptors exposed in different European sites. Finally the paper will conclude on the remaining challenges in developing the library and the results in terms of valuing coastal flood impacts.

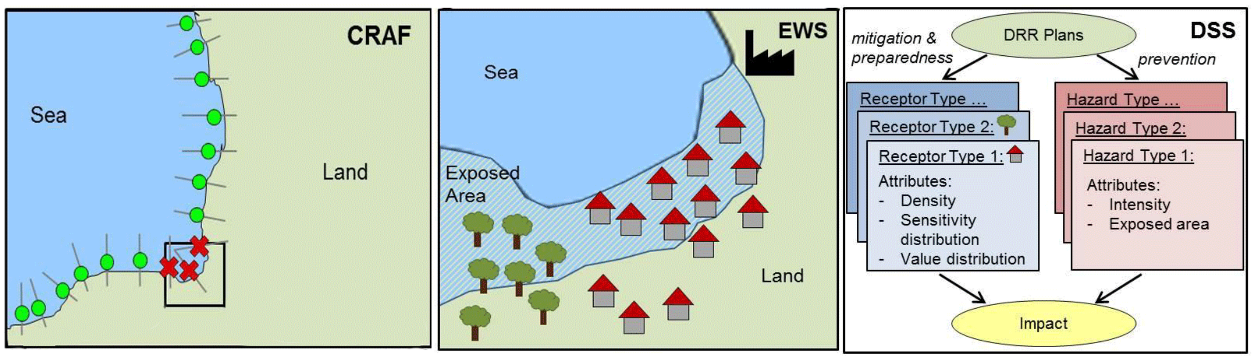

Figure 1: Conceptual Drawing of the Risc-kit toolKIT

1. FRAMEWORK FOR ASSESSING VULNERABILITY AND IMPACT

Following the Brundtland Commission (WCED, 1987), the European Commission promotes the sustainable development of our society. From a natural hazard perspective unsustainable development can be interpreted as the lack of ability for a system or a sub-system to return to a state similar to the one prevailing prior to disaster (Birkmann, 2006). Turner et al. (2003) indicate that the “resilience of the system is often in terms of the amount of change a given system can undergo and still remain within the set of natural or desirable states”. Sustainable development also means that the stakeholders’ perspective should be captured to better understand the desirable states (Fiksel, 2006). This remains an important challenge and adds complexity to the characterization of the system as different stakeholders may have different perspectives, needs and purposes and therefore approach systemic sustainability differently (Green et al., 2011). Sustainable development also means that the desired outputs can be characterised as ‘well-being’ (Stiglitz *et al.*, 2009), a multi-dimensional concept which cannot be reduced to a single measure such as GDP value. The concept of sustainable development, therefore, challenges us in the way we traditionally approach the assessment of natural hazard impacts and forces us to revise our methodologies.

As such, in the RISC-Kit project, risk is defined as the product of the *probability of a hazard and its consequences.* These consequences (or impacts) are composed of two factors: the direct exposure (the density of receptors, e.g. number of people and buildings in an affected area) and vulnerability (receptor value and their sensitivity to experience harm). The current definition takes its origin in the Source-Pathway-Receptor model (Gouldby et al., 2005). The SPR approach focuses on assessing direct losses and attempts to measure the first order of losses (e.g. business disruption for flooded business) and is commonly employed in the field of economic loss assessment applied to natural hazards. The approach has its advantages but neglects higher order of losses, also called indirect losses or induced losses (Messner et al., 2007; Penning-Rowsell et al., 2013; Rose, 2010). Turner et al. (2003) challenge the risk-hazard (RH) model and the PAR model (Pressure-and-release Model) in this regard. Przyluski and Hallegatte (2011) highlight for instance that a better understanding of the interaction between the economic intrinsic dynamics (e.g., business cycles) and external shocks (e.g., from natural hazards) is required for identifying the relevant process. To do so Rose (2010) proposes to change radically the current assessment approach by considering flows rather than stocks and by better integrating the time dimension. In the RISC-KIT project, this problem is also recognized. Therefore limiting the development of vulnerability indicators only to the assessment of the perturbations and stressors is insufficient for understanding the overall consequences of an event and it is necessary to better consider the resilience of interconnected systems.

Vulnerability has many different connotations in the literature on hazards, depending on the research perspective (Dow, 1992; Cutter, 1996, 2001a). Broadly, there are three main positions in vulnerability research (a) the identification of conditions that make people or places vulnerable to extreme natural events, an exposure model (Burton et al., 1993; Anderson, 2000); (b) the assumption that vulnerability is a social condition, a measure of societal resistance or resilience to hazards (Blaikie et al., 1994; Hewitt, 1997); and (c) the integration of potential exposures and societal resilience with a specific focus on particular places or regions (Kasperson et al., 1995; Cutter et al., 2000). The last definition, vulnerability to hazards as 'the potential for loss' which varies over time and space, remains the most appropriate for the objectives of our research. However just approaching vulnerability as a combined sensitivity-value function is problematic considering the necessary improvement in the impact assessment. Menoni et al. (2010) have recognized this problem and have proposed an alternative vulnerability framework (Figure 2) by recognizing four groups of vulnerability: Physical vulnerability (sensitivity of receptors in direct contact with the hazard), Systemic vulnerability (propagation of the losses through different systems within and beyond the hazard area), Resilience as the capacity to transform losses into opportunities and resilience as the mitigation capacity. A comprehensive and meaningful understanding of the vulnerability of the coastal system can only be achieved through a holistic analysis of various components of vulnerability. Therefore in this paper we have adopted this framework and applied to the following categories: built environment, human population, ecosystems and critical infrastructure.

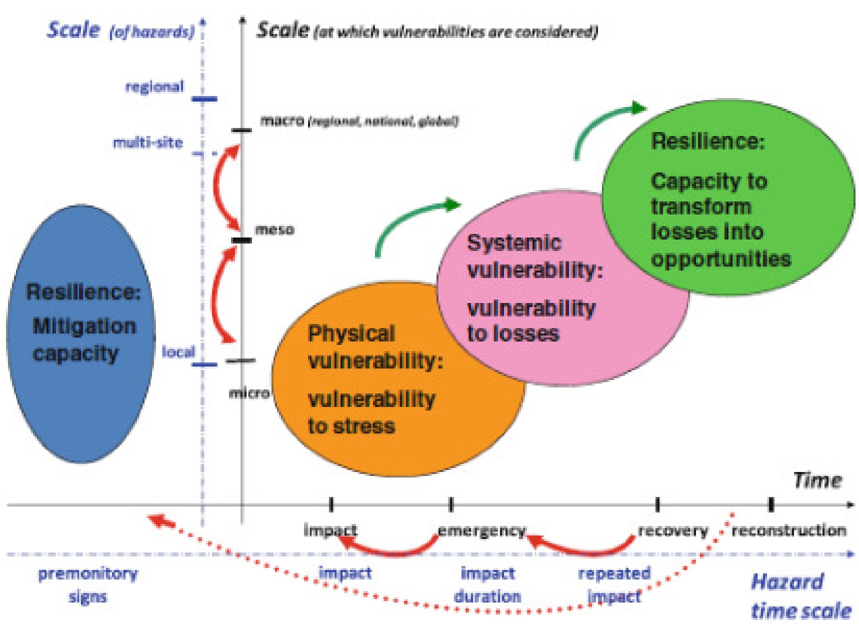

Figure 2: The ENSURE vulnerability framework (From Menoni et al., 2010)

2. PHYSICAL AND SYSTEMIC VULNERABILITY: MODELS AND DATA

To establish the structure of the vulnerability indicator library, existing models to assess vulnerability and the associated data have primarily been collected from existing European and National datasets supplemented by an exhaustive literature review. Data from the RISC-KIT sites are also collected to complement and address regional variability in Europe. The analysis of these regional and local data is still under progress and will be presented at the conference. At this stage of the project the assessment has also been limited at two groups (Physical and Systemic Vulnerability). The Resilience will be investigated later in the project and is therefore not addressed in this paper.

2.1 Physical Vulnerability

Physical vulnerability addresses the question of the sensitivity of receptors directly in contact with the water and their associated loss value. Understanding the sensitivity is essential to measure the initial shock before it propagates through the considered system. The sensitivity determines the potential losses to an asset which may occur by physical, chemical and biological processes. The physical sensitivity depends on the characteristics of the considered elements but also on the characteristics of the hazard (e.g. water depth, velocity, duration, pressure, loads). The following sections discuss the sensitivity associated with the built environment, the population and the ecosystem.

Built environment

Built environment includes different types of man-made assets such as buildings, vehicles and infrastructure. The direct contact of such assets with water generates the damages to the asset structure and its contents, i.e. either it has to be repaired or replaced. The sensitivity value is commonly called susceptibility (i.e. representing a degree of loss in the form of a percentage) and associated or combined with a monetary value. In Europe, the so-called depth-damages curves are commonly developed in most northern countries (Figure 3) as a means to assess the potential damages to residential and non-residential assets and to perform cost-benefit analyses. However, differences in what they represent, in the quality and the quantity of primary data and in the methodology, make their comparison or their harmonization difficult, although attempts have been made (Jongman et al. 2012). In particular, very few data are available for southern countries (e.g. Portugal, Spain, and Italy). Despite the existence of depth damages curves the requirement for a better framework for data collection and validation protocol is demanded in Europe (Meyer et al.,2013, Molinary et al.,2014). The depth-damage curves are also primarily developed in the context of fluvial flooding, an uplift factor being applied to mimic the added effects of salt content and wave effects. Another issue is the question of extreme and unusual hazard characteristics and the possibility of building collapse. In such case a different model needs to be applied. A current model takes the form of a risk collapse matrix indicating a degree of collapse for different types of building fabric and for different depth-velocity values. However very few studies (Karvonen, 2000, Roos, 2003, Kelman and Spence, 2004) provide such information and the matrix can only be provided as a basis for assessment with caveat on the high uncertainty associated with such a matrix.

Risk to life and injuries

Loss of life due to floods exists. However this risk is very low compared to other disasters, and high loss of life due to floods mainly occurs in developing countries. In Europe, the average event mortality is estimated at 4.9*10-3 for river flood and at 3.6*10-2 for flash floods stressing a higher risk of death in flash floods (Jonkman et al., 2008) and the low records of death limits an empirical analysis of risk to life. In addition, there are numerous factors and characteristics (including, but not limited to: social, physical, political, cultural and environmental) which lead to a loss of life during flood events (Jonkman et al., 2008). The most important determinants of the number of fatalities can be highlighted, but quantifying again remains tentative. In Europe, the risk to life model proposed by Priest et al. (2007) takes into consideration many of these important aspects (e.g. depth-velocity thresholds, social characteristics, building type and characteristics) in the form of a risk matrix and proposes a descriptive output highlighting potential outcomes in terms of risk to life.

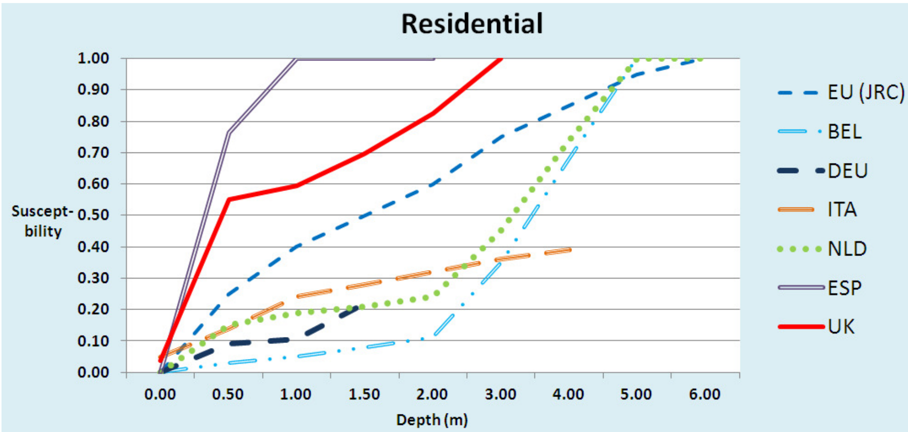

Figure 3: Susceptibility Curves for Residential Property in Europe

Ecosystem

Coastal habitats are already heavily degraded in European regions predominantly as a result of erosion, human development, sea level rise and the increase in the intrusion of saline waters into freshwater environments following a storm (EEA, 2010, Nicholls and Klein 2005, Nicholls and de la Vega-Leinert 2008, EEA 2006). Coastal ecosystems are adapted to face coastal storm and therefore their conservation can be promoted by an ecosystem-based approach. However these systems even if adapted may need time to recover and this recovery will depend on their status, on the existence of alternative habitats, on other existing pressures and on human management in their recovery. In certain circumstances a single storm may induce a change of ecosystem from grassy dunes or maritime forest to bare sand for instance (Burkett et al., 2005). Coastal ecosystems include estuaries and marshes, lagoon and salt ponds, intertidal zone but also other ecosystems such as agriculture, forests, freshwater, groundwater are not adapted to coastal flooding and have also to be considered. During their recovery they may not fully provide these services and, therefore, a vulnerability assessment should carefully consider the potential changes in delivering these services. Assessing the physical vulnerability assessment of ecosystem therefore requires indicating how a storm may reduce or alter the delivery of important ecosystem services. Some progress has now been done on assessing the impact of coastal flooding on various ecosystems (Hoggart et al., 2014). Yet the challenges still remain in developing vulnerability indicators to represent these impacts. Barbara et al. (2014) however have developed an interesting vulnerability indicator model expressing potential changes (e.g. Negligible, transient effect, semi-permanent, permanent change) in a habitat following a flood regime for different type of coastal ecosystems. The combination of such model with potential ecosystem services reduction could be the way forward. Expressing ecosystems services reduction could be approached quantitatively. For instance, crops can be grouped according to their tolerance to soil salinity or irrigation salinity and then a relative crop yield derived (R.S. Ayers and D.W. Westcot (1994)) (Penning-Rowsell et al., 2013). If not, local knowledge provided by stakeholder might provide an alternative and valid approach to empirical data.

2.2 Systemic vulnerability

Understanding the ripple effects necessary to evaluate systemic vulnerability includes the recognition of critical networks (e.g., electric supply, water distribution, transportation) vital for the economy but also less observable networks such as the supply-chains network, community, and health impacts. Whereas current assessment approaches simply identify node points (or receptors), assessing system vulnerability requires the identification of the links between these points, the capacity or flow attached to these links but also the functional relationship between inputs and outputs at each node (Green et al., 2011). From this perspective, systemic vulnerability can then be described as the chain of interrelationships between the initial points at which the perturbation impacts the system and as the capacity of a given system to continue functioning despite some level of disturbance. In other words systemic vulnerability may be expressed as the analysis of functional dependence of one component on the others. Dependence analysis is the key to systemic vulnerability assessment. A first challenge is to then transfer the physical vulnerability into systemic vulnerability, e.g. how the initial shock on particular nodes propagates through a set of networks and ripples onto other nodes of the system. Disruption therefore, is the link between physical vulnerability and systemic vulnerability. Disruption needs to be expressed as a loss of flows over a defined period of time rather than a loss of stocks, similar arguments as expressed by Rose (XXX). A second challenge lies in modeling the propagation of the impacts through different systems. It may be difficult to provide a common conceptual model to characterize the vulnerability of these systems. However the following key points have to be considered:

- Characteristics of nodes and networks: functions of production, flows and capacity, typology
- Dependencies and interdependencies
- The degrees of uniqueness of given functions which may be lost temporarily.
- Prioritisation of some functions is vital for more than one system.
- The potential for functional surrogates or substitutes surrogate for lost functions and transfers of functions in space and possibly also time.
- Degrees of influence
- The boundaries may be not limited to the territorial space.
- Scale effect
- Pre-existing vulnerability / non optimal/optimal system under normal condition

What is required is not only a conceptualisation of systemic vulnerability within a territorial system, but also one which leads to a methodology which may be used to assess systemic vulnerability in any circumstance. The model could be descriptive and analytic. But computer modelling may also provide a way forward. Most of the literature in this area focuses upon models for analysing disaster impacts. The most widely used model is economic in character and is Input-Output (IO) analysis developed by Leontif in the late 1920s/early 1930s. It has been used in recent decades by Cochrane (1974, 1997; Kawshima et al., 1991; Islam, 2006). Computable General Equilibrium (CGE) models CGE models, econometric models, Social Accounting Matrix (SAM) methodology are other approaches used in this area (Okuyama, 2009; Stone, 1961, Cole, 2004). These models however do not investigate specifically the problem of vulnerability and remains limited to economic impacts assesment at macro-scale. Since the consequences of a shock on a system are dependent upon the structure of the system, there is a need for models which are more realistic in the representation of the propagation. The use of agent-based modelling and general systems modelling (Castle and Crook, 2006) may give greater understanding of what are the critical issues in the effects of a shock on an economic system. Agent-based modelling of disaster vulnerability and impacts currently appears to be in its infancy (e.g. Naqvi, 2012; Crooks and Wise, UD) Currently, most of the agent-based models applied to disasters seek to model evacuation behaviour (e.g. Chen and Zhan, 2008) or disaster rescue (e.g. Marecki et al, UD). However, recent research on dependancy analysis (Pascale et eal.,2010;Pitilakis and Argytoudis, 2013) could be adapted to an agent-based modelling approach.

3. CONCLUSIONS

A comprehensive and meaningful understanding of the vulnerability of the coastal system can only be achieved through a holistic analysis of various components of vulnerability. That means that the assessment should not only be restricted to the initial losses associated with the physical vulnerability but should better address the propagation of these losses. To do so, it remains essential to better characterize the vulnerability of the different sub-systems embedded on the coast and to develop innovative modeling approaches. One pre-condition remains the availability of data. Methods for assessing direct costs to the built environment, the population and the environment have been developed in most parts of Europe, though their application remains limited to either specific or generic types of receptors, to certain European regions, or to certain conditions and their transferability to others is questionable. But this evaluation remains nevertheless essential for understanding the sustainability of coastal system in the face of extreme threats. Therefore, the significant issues remaining in terms of data collection and availability to enable validation and to reduce the uncertainty associated with their assessment should not stop efforts in valuing coastal efforts but should be recognized and highlighted. To the question can we really value coastal flood impacts? The answer is probably not from a quantitative perspective. But progress has been made, and our better understanding can help decision makers or at least highlight for them the possible consequences of a comparative assessment.

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