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VULNERABILITY AND RISKS RELATED TO CLIMATIC EVENTS IN URBAN COASTAL ENVIRONMENTS: OVERVIEW OF ACTUALITY AND CHALLENGES OF METHODOLOGIES AND APPROACHES

Giuseppe T. Cirella[a,b], Felix O. Iyalomhe[b], Alessio Russo[c]

[a] *Institute of Earth Sciences, Department of Regional Policy and Political Geography, Saint Petersburg State University, Saint Petersburg, RU*
[b] *Polo Centre of Sustainability, Imperia, IT*
[c] *Laboratory of Urban and Landscape Design, School of Arts, Culture and Sports, Far Eastern Federal University, Vladivostok, RU*

HIGHLIGHTS

- Overview research methodologies of urban coastal vulnerability and risk assessment.
- Linkage of vulnerability assessment to urban coastal ecosystems and ecosystem-based approaches for urban coastal risk assessment.
- Climatic events and natural hazards research.

ABSTRACT

International-renowned forecasting of urban development in coastal environments indicates an increased exposure to the risks of climatic events by way of natural hazards. This indication indirectly exacerbates the vulnerability of relating coastal communities. Using this viewpoint, a decade long study between 2000-2010 conceptualises a considerable volume of research in the area of vulnerability to urban environmental change due to disasters in relation to climatic events. In particular, several studies have attempted to present a discourse on the vulnerability of social ecological systems to hazards or risk occurrence within urban coastal environments in order to improve understanding and support for the assessment of impacts and risks related to such change and, by definition, its associating adaptive measures. This overview takes into account disparate opinions, approaches and methodologies applied by different scientific viewpoints and research studies, and highlights salient and vantage aspects. The research is organised in three key methodological sections: (1) urban coastal vulnerability and risk assessment; (2) vulnerability assessment of urban coastal ecosystems; and (3) ecosystem-based approaches for urban coastal risk assessment. Vulnerability and risk assessment are anchored via exposure, susceptibility and resilience, and are must-do activities when addressing a system.

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gt.cirella@polocentre.org, fo.iyalomhe@polocentre.org, russo.a@dvfu.ru

1. INTRODUCTION: THEORETICAL CONCEPTS OF VULNERABILITY

Over the past two decades, studies have shown that vulnerability is not only a central concept to climatic events but to a number of other research contexts (e.g. geography, poverty and development, natural hazard, ecology, public health, sustainability studies, secure livelihood and famine and land use) (Schroter et al., 2005; Brooks, 2003; Füssel, 2006; Downing et al., 2001; Kelly & Adger, 2000; Adger, 2006; O'Brien et al., 2004; Downing & Patwardhen, 2003; Cardona, 2003; Kumpulainen, 2006; Tuner et al, 2003). Consequently, the term vulnerability has been framed in many different ways by these research communities, confusing its formal concept and definition. In order to clarify this jargon, several studies argue that vulnerability would be meaningful if it only refer to a particular vulnerable situation or system (Füssel 2006). Moreover, Brooks (2003), Downing and Patwardhen (2003), Luers et al. (2003) and Füssel (2004) propose a conceptual framework for vulnerability which specifies the following components: system (i.e. region, population or sector), hazard (i.e. threat or stressor), consequences (i.e. effects or variables of interest) and a temporal reference (i.e. period of interest). Similarly, Ionescu et al. (2008) describe vulnerability as relative in that it must specify: (1) the entity that is vulnerable; (2) the stimulus to which it is vulnerable; and (3) the preferred criteria must estimate the outcome of the interaction between the entity and the stimulus.

From the outlook of natural hazard communities and climatic events, Brooks (2003) opined that natural hazards emphasise risk in terms of probability, while climatic events emphasise risk in terms of variable factors (e.g. hazard and social components of a system). Accordingly, Füssel (2006) claimed there is no single or best conceptualisation of vulnerability since the risk-hazard framework indicates hazard and vulnerability as determinants of risk, while risk differs from vulnerability as it is contingent on hazard. This is confirmed by Kumpulainen's (2006) concept of vulnerability in which risk is expressed as a function of both hazard potential and vulnerability. Moreover, vulnerability does not depend solely on the internal characteristics of a system but also considers the damage potential of the hazard and its coping capacity. It also takes into account the three dimensions of a system (i.e. environment, social and economic) in order to formulate an integrated vulnerability index when addressing a system – in itself. Contrary, Brooks' (2003) definition of hazard is framed as a sole determinant of vulnerability and equates risk with biophysical vulnerability, while Romieu et al. (2010) connects the context to episodic or intense events. All in all, the endpoint of vulnerability assessment, in terms of natural hazards, is tailored toward risk assessment interacting with hazard exposure evaluation, versus vulnerability on climatic events ending with vulnerability assessment. Additionally, Dolan and Walker (2003) identify three key characteristics: (1) vulnerability is expressed in terms of exposure to physical event placing people at risk or under hazardous circumstance; (2) vulnerability is a function of the human relationship and not a physical event, in other words, the social conditions and circumstances that put people at risk via diverse ranges of shock or stress; and (3) vulnerability integrates both the physical event and social conditions that place people at risk via exposure with limited capacity to adapt. Several studies have proposed a number of methodologies for coastal environment vulnerability assessment, agreeing on a conceptual framework (Szlafsztein & Sterr, 2007), in which urban development and coastal community concepts are applied.

2. METHODOLOGY

In this paper, we provide an overview of different opinions, approaches and methodologies applied by different scientific viewpoints and research studies, and focus on salient and vantage aspects. Our analysis of the overview overlooks research between 2000-2010, and is based on the review of academic literature and reports from national governments and international agencies. The research is organised into three key methodological sections: (1) urban coastal vulnerability and risk assessment; (2) vulnerability assessment of urban coastal ecosystems; and (3) ecosystem-based approaches for urban coastal risk assessment. We afford the use of a system to Brooks' (2003) definition and apply it in an urban development context.

3. URBAN COASTAL VULNERABILITY AND RISK ASSESSMENT: METHODOLOGIES AND APPROACHES

The assessment of vulnerability has proven to be a central concept for understanding the major impacts of natural hazards and climatic events and, for developing robust risk management strategies (Kaiser, 2007). In particular, vulnerability assessments are useful methodologies to investigate climatic concerns on ecological and human systems. In fact, they constitute an extension of an impact assessment aimed at: (1) producing information that helps to understand how a system is potentially affected by and responds to a change in climatic conditions; (2) contributing to policy making by presenting information to stakeholders; and (3) recommending adaptation measures and facilitation of sustainability (Füssel & Klein, 2002). In this context, several relevant approaches proposed and applied for the assessment of impacts, vulnerability and risks related to climatic events and natural hazards are appraised within an urban coastal setting.

Starting from the perspective of urban developmental hazards connecting with climatic events, an interesting approach given by Harris et al. (2010), assesses physical vulnerability to coastal hazards in which long term trends or impacts of variable climate and individual events (e.g. storms, floods) can leave many coastal communities at risk. Any increase in frequency and intensity of coastal hazards or projected acceleration of sea level rise call for adequate incorporation of impacts of climatic events and variability into urban coastal vulnerability assessment. Accordingly, a described integrated approach was done via multi-scale and multi-hazards analysis. The example research, recorded in the southern region of Oregan, USA, observed scenarios of decadal trends and future impacts of these hazards with the aim of establishing a framework that would promote and support science-based decision making at the urban coastal scale.

A further attempt to investigate the vulnerability of coastal communities to climatic events and related risks (e.g. storm surges) examined possible impacts on sandy beaches (e.g. inundation, sediment transport, erosion, infrastructural damage) was explore by Mendoza and Jimenez (2008). The methodological framework was implemented through an approach shown in Figure 1. This approach was applied to the north eastern parts of Spain's Mediterranean coast (i.e. Catalan region) to assess and estimate the vulnerability of storm impacts as a quantitative value of the coast vulnerability index. Although this methodology can be applied with limited data and simplification, its usefulness shows particular qualities in its dynamic, deconstructive nature of coastal regions. Moreover, a probabilistic approach was also employed to assess the vulnerability of regional urban coasts to storm-induced impacts by Bosom and Jimenez (2011), in order to estimate the probability of hazards occurrence and the comparison of hazards and vulnerability associated with this occurrence to the Catalan region; the study provides spatial distribution of hazards along the coast and ensures the comparison of urban coastal vulnerability at the regional scale to storm-induced (e.g. erosion, inundation) associated with a given probability.

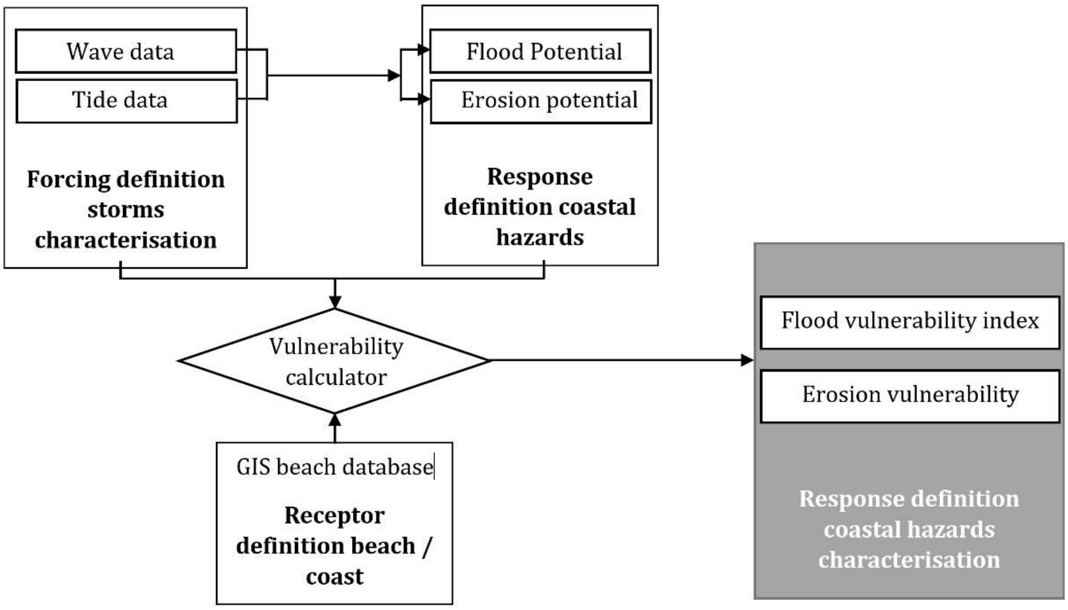

Figure 1: Methodological approach to assess coastal vulnerability to storms. *Source: Adapted from Mendoza and Jimenez (2008)*

Climate events associated with sea level rise has been seen as major environmental concern, especially in urban coastal regions. This emergence has called for urgent scientific methodologies and tools to assess the vulnerability of urban coastal zones to sea level rise and associated impacts. Accordingly, Natesan and Parthasarathy (2010) proposed a methodology that considered Digital Elevation Model (DEM) combined with overlaying techniques in a GIS environment, in order to determine inundation zones along the Kanyakumari coastal region in India. This approach involves the generation of topographical maps of the area, using DEM and analysis of inundation zones according to the various sea level rise scenarios. The outputs were overlay with theme maps of land use, sensitive areas, tourist spots and coastal villages, in order to estimate the areas and inundation distance that could be exposed to various sea level rise scenarios. In other words, the exposure maps of areas that could be permanently inundated by sea level rise were produced to support the definition of coastal zone management practices that could be taken into account to protect human life and urban and infrastructural development. The major setback of this methodology lies in the robustness of the DEM data that is a prerequisite for the computation of spatial inundation zones. Further research includes Gravelle and Mimura (2008) which take into account the DEM and precise inundation of a Design Water Level layer consisting of tidal values, sea level rise projections and storm surge, in order to estimate coastal vulnerability and, identify areas at high risk to the impacts of sea level rise. This methodology can be extremely useful in identifying high risk urban locations within a system, in order to support the adaptation process and, the validity of GIS data used. However, the analysis is not full proof due to zonal complexity and variation. Further GIS-based modelling includes Bryan et al.'s (2001) environmental parameters and urban coastal vulnerability methodology via the use of statistical class relationships (Harvey et al., 1999) and Torresan et al.'s (2008) comparative analysis approach to vulnerability assessment of regional scale research of Veneto's urban shoreline in Italy. Problems include the quality of data available by way of global scale analysis and the complexity of required geometric modelling.

Ozyurt and Ergin (2009) offer a more scientific approach to assessing coastal vulnerability to sea level rise through a coastal vulnerability assessment model that is based on a vulnerability matrix and index, and considers physical parameters (e.g. rate of sea level rise, coastal slope, geomorphology), to represent the physical processes of impacts of sea level rise (i.e. coastal erosion, inundation, salt water intrusion), and human influence parameters (e.g. natural protection degradation, land use pattern, coastal protection and structure) to represent the direct and indirect human activities to an urban coastal region. Great concern to these regions have been examined worldwide with several vulnerability assessment methodologies developed and applied.

Throughout Australia the Coastal Sensitivity Index (CSI) put together by Abuodha and Woodroffe (2010) elucidates one such application. The CSI application considers six structural semi-quantitative variables and three process variables using ArcGIS. The application implements data availability and lacks several processes that do not equate high quality indicators for urban coastal sensitivity assessment. Moreover, Dwarakish et al. (2009) describe another important method via a vulnerability assessment approach that determines the potential effects of coastal erosion and inundation. Their application is very similar to Abuodha and Woodroffe's (2010), in that, variables considered and computational method developed make up a Coastal Vulnerability Index (CVI). The CVI has been applied and is somewhat beneficial to urban coastal development even though it often has low resolution and limited extrapolative data. Finally, Anfuso and Martinez Del Pozo (2008) describe the combination of GIS and aerial images to analyse the vulnerability of coastal shorelines to erosion. The application involves the analysis of spatial data taken by aerial photography and satellite imagery to show differences in coastal evolution over time (i.e. erosion, accretion) and land use derived from observation – offering an evolutionary method to urban development and planning.

4. VULNERABILITY ASSESSMENT OF URBAN COASTAL ECOSYSTEMS: METHODOLOGIES

The complexity of urban coastal systems coupled with vulnerability and increasing pressures from climatic and anthropogenic sources, calls for long term potential impacts and response assessment. In order to achieve this objective, it must be recognised that urban coastlines are an integrated system and, as a result, implementation of integrated management frameworks, like shoreline management planning for flood and erosion hazards, are indeed necessary. Against this backdrop, Mokrech et al. (2009) demonstrate the possibility of developing and applying an integrated framework that is multi-scale and capable of linking various models to simulate complex coastal processes and, consequently, allow for long term assessments that are useful for developing future management plans. To this end, the system employs an integrated framework that permits simulation of three distinct scales: global, regional and local. It incorporates the inclusion of socioeconomic scenarios in which the potential impacts of flood and erosion and possible linkages to urban coastal zones can be observed.

Climate events are not only evident in the general coastal environment but also in specific ecosystems such as groundwater resources which are considered very important water source for urban or rural development. As a result, groundwater resources are more vulnerable to pollution than the surface water, especially, in semi-arid and arid regions where there are large amounts of water extraction from these resources. Hence, sustainable management of these resources demand innovative approaches useful to assess the vulnerability of groundwater resources. To this end, Jamrah et al. (2008) propose the DRASTIC vulnerability index methodology using a GIS environment to study the variation in groundwater vulnerability to pollution. In this method, DRASTIC layers are created from records of the area based on the following parameters: D – depth to the water table from the soil surface, R – net water recharge, A – aquifer medium, S – soil medium, T – topography, I – impact of the vadose zone and C –conductivity or hydraulic of the aquifer. These parameters are rated and assigned weights to reflect their effects and relative importance on aquifer vulnerability and by linear combination estimate long term changes. Such maps can be further analysed using groundwater quality data such as chemical and biological parameters and can contribute to urban development planning by clarifying spatial variations in calculating vulnerability to pollution influences.

Similarly, both short term and geological records show that urban coastal wetlands are particularly sensitive and vulnerable to changes within coastal environments (McFadden et al., 2007). In particular, the sensitivity and vulnerability of such wetlands to sea level rise and tidal inundation would change their extent, position and type, as accelerated sea level rise increases it is forces itself upon wetland systems (Richards et al., 2008). In an urban context, these wetland changes have often involved large scale infrastructural alteration. Notable examples from around the world include the Gold Coast, Australia inlands; the Mumbai, India shoreline; large parts of the Netherlands; Rio de Janeiro, Brazil; and the Chicago, USA shoreline. In this context, McFadden et al. (2007) present a methodology called Dynamic Interactive Vulnerability Assessment (DIVA) Wetland Change Model that incorporates broad scale modelling of wetlands in order to carry out dynamic and integrated assessments of regional and global change patterns of coastal wetland vulnerability and wetland lost. This promotes the assessment of relative sea level rise, sediment transport and coastal protection in affecting wetland vulnerability – essential to urban development and assessment processes. The DIVA Wetland Change Model transforms dynamic assessment of wetland vulnerability into categories of wetland loss and transition, that is, it captures broad scale responses of wetland to sea level rise and other key drivers such as human impacts like: dyke construction, wetland nourishment, sediment supply, tidal range and accommodation space. Note, the environmental forcing of parameters is less accurate at the regional level where local data may override broad scale control and lack suitable inputs to validate results. This model still remains a challenge and exemplifies the complexity of vulnerability assessment methods of urban coastal ecosystems.

5. ECOSYSTEM-BASED APPROACHES FOR URBAN COASTAL RISK ASSESSMENT

In addition to vulnerability assessment methods, risk assessment methodologies are widely employed to evaluate the consequences of climate events risk and associated hazards to urban coastal systems. Sharples et al. (2008) describe a major spatial coastal risk assessment approach which is framed in a simple conceptual framework involving three logical "passes" to estimate the physical sensitivity and exposure of coastlines to hazards such as storm surge, flooding and erosion. According to them, the first pass identifies those shores likely to be physically sensitive to coastal hazards, taking into account the geomorphic and topographic features that could make the shore erosion prone and low-lying areas flood prone. The second pass assessment focuses at the regional level to identify variations in the process driving the impacts on sensitive shores, in order to identify those shores exposure to physical impacts by using information based on the wave climate, tidal regimes and storm activities. This leads to the third pass assessment which is local (e.g. urban site-specific) to determine variations in shoreline sensitivity and exposure, as a basis for the definition of robust responses to the identified hazards.

The New Zealand Ministry for the Environment (2008) describe a risk assessment process based on the New Zealand standard for risk management in the context of urban coastal zones which identify and characterise the main features of risk, and qualitatively or quantitatively estimate the risk and compare it sources. It also assesses the impacts of lack of knowledge within the context of decision and the potential effectiveness of solutions to manage the risk. This ecosystem-based risk assessment approach for hazards has been stressed to be related to climatic events in coastal zones, distinct steps include: (1) definition of the problem or objectives that need to be addressed and its actual context (i.e. boundaries, both spatially and temporally); (2) identify the relevant urban coastal hazards and climatic drivers (i.e. understanding coastal community prevalent hazards, vulnerability and exposure to damage and its change over time – see Source-Pathway-Receptor-Consequences (SPRC) framework in Figure 2); (3) assess the likelihood and magnitude of the hazards occurring (i.e. potential hazard source and likely pathway to potential receptor estimation); (4) assess the scale of the hazard consequence on the receptor (i.e. estimation of potential or present receptor vulnerability within the coastal community); and (5) evaluation of the coastal hazard risk (i.e. combination of the magnitude of hazard occurrence and magnitude of the vulnerability of receptors and the coastal community). Within the context of an urban coastal zone, SPRC illustrates drivers and how they can impact on a range of human and built environments.

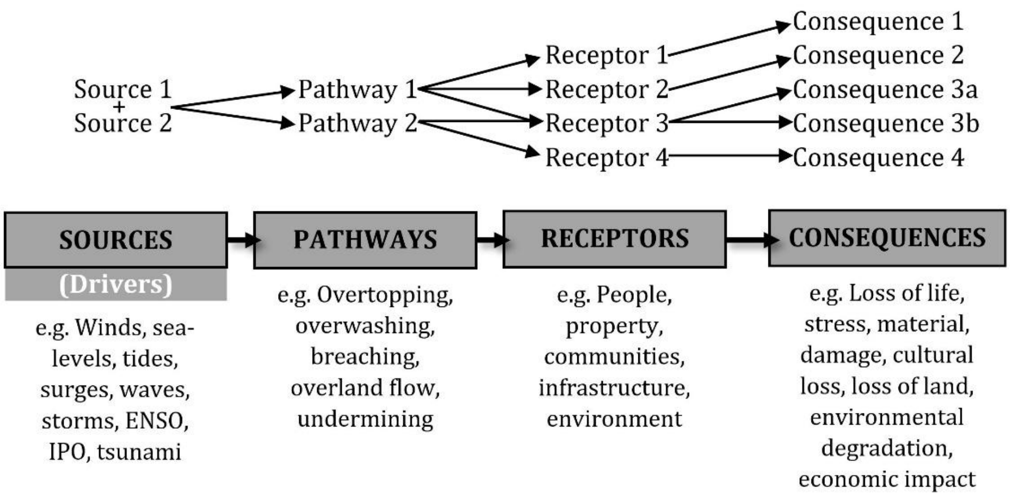

Figure 2: Source-Pathway-Receptor-Consequences framework for assessing urban coastal hazard risk. *Source: Adapted from New Zealand Ministry for the Environment (2008)*

Ecosystems and services decline especially in Small Island Developing States (SID) due to population pressure. This has been proven to be a driver for natural hazard and climatic events impacts (UNEP 2010). Despite numerous assessments, there has been critical investigation on how SID environmental factors can alter patterns of risk and vulnerability. As a result, ecosystem-based risk reduction options have not been identified. This has led to the initiation of Risk and Vulnerability Assessment Methodology Development Project (RiVAMP) by the UNEP. RiVAMP is a methodology that takes into account environmental factors in the analysis of disaster risk and vulnerability. It considers ecosystems and climatic events in the risk assessment process and uses evidence-based, scientific and qualitative research to show the role of ecosystems in disaster risk reduction. Accordingly, it employs an assessment framework, which involves: ecosystems and their services, environmental change due to human activities and climatic events, vulnerability and local livelihoods and environmental policies – in order to indicate human interaction with ecological systems and indicate drivers of ecosystems degradation. RiVAMP combines local knowledge base via stakeholders, GIS, statistical analysis and hydrodynamic modelling of coastal ecosystems' buffering effects on coastlines under the influence of sea level rise and storm surges. The results have been useful for urban ecosystems and environmental degradation management, and associated potential risk to urban coastal areas. RiVAMP is another method of better informing policy makers on sustainable urban management through improve urban ecosystems management.

6. CONCLUSION

There is a considerable number of studies in the concept and assessment of vulnerability, for which there are many methodologies derived from differing applications of conceptual models, approaches and frameworks. From the perspective of this decade long overview, vulnerability is a concept that is very much connected with exposure to physical events that are harmful, and to the degree of sensitivity by which climatic events or natural hazards are triggered. In order to increase urban resilience, urban planners should incorporate vulnerability into resilienc-based methods, taking into consideration climatic uncertainty by way of risks and physical and socioeconomics aspects (Abdrabo & Hassaan, 2015). Indeed, we argue that vulnerability and risk assessment are anchored on the three pillars of exposure, susceptibility and resilience; hence, vulnerability assessment is a must-do activity necessary to determine the relative risk of areas within an urban community and its careful, safe development. Addressing why they are at risk and how to address the risky situations remains imperative.

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