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Community vulnerability to coastal hazards: Developing a typology for disaster risk reduction

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ABSTRACT

Coastal communities around the world face challenges in planning for coastal flooding and sea-level rise related to climate change. This paper develops an approach for identifying typologies of communities on the basis of their hazard vulnerability characteristics. The approach first characterizes communities with a suite of vulnerability indicators, selected to meet criteria of breadth, relevance, and data requirements. Cluster analysis is then applied to the indicator profiles to identify groups of similar communities. The statistical centrotype of each group represents the corresponding community type. A new community from outside the original set can then be matched to the typology using a Hazard Vulnerability Similarity Index (HVSI). The approach is demonstrated with a case study of 50 communities on Canada's Pacific coast. Results yielded 10 community types, of which four were predominant. The types range from highly urbanized, wealthier, diverse central cities to remote, resource-dependent towns with semi-developed, flat coastlines. Three selected communities from a distant region, in Atlantic Canada, were then successfully matched to the most similar of these 10 types. Identifying groups of communities that share vulnerability profiles can facilitate sharing knowledge, lessons, and resources that are most relevant to local efforts to reduce natural hazard risk. This support may be especially valuable for connecting communities that are unfamiliar with one another, yet similarly vulnerable.

1. Introduction

Around the world, coastal communities face hazards such as coastal flooding and sea-level rise related to climate change (Revi et al., 2014). Total potential losses from flood hazards are increasing rapidly in major coastal cities (Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013). While many cities have initiated adaptation to coastal hazards through planning and engineering efforts, others lack the knowledge and resources to implement appropriate risk reduction measures (Araos et al., 2016; Bierbaum et al., 2013). The multidimensional nature of climate impacts and growing demand for knowledge to support adaptation necessitate exchange through social learning networks that span multiple sectors and communities (Bidwell, Dietz, & Scavia, 2013). The proliferation of urban climate adaptation and resilience networks (e.g., 100 Resilient Cities, C40 Cities Climate Leadership Group, ICLEI–Local Governments for Sustainability) attests to the increasing demand among communities to share knowledge and resources on risk reduction strategies, experiences, and lessons.

Knowledge sharing may be especially valuable between communities with similar vulnerability characteristics (Chang, Yip, van Zijll de Jong, Chaster, & Lowcock, 2015; Wood, Jones, Spielman, & Schmidtlein, 2015). Vulnerability, which has been conceptualized in multiple, evolving, and sometimes incongruent ways in the literature (Wisner, 2016), is here defined as attributes of communities that affect the potential for harm when hazard events occur. Vulnerability arises as “a function of the exposure (who or what is at risk) and sensitivity of the system (the degree to which people and places can be harmed)” (Cutter et al., 2008, p. 599). Factors such as coastal geomorphology, urban development patterns, wealth, and socio-economic structures affect how a given coastal hazard event would lead to human losses, property damage, and economic disruption (IPCC 2012). To be effective, therefore, risk reduction and resilience strategies must consider the local hazard and vulnerability context, as solutions appropriate for some types of communities may be unsuitable for others (Wood et al., 2015).

This paper contributes to the emerging literature on patterns of vulnerability across places. Numerous studies have advanced understanding of vulnerability by identifying localities that are highly vulnerable, thereby focusing policy attention and resource allocation. Recent scholarship has advocated a complementary goal: recognizing

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how places may be similarly vulnerable, regardless of whether or not they are highly vulnerable, in order to facilitate knowledge exchange for risk reduction. To address this need, this paper develops a method for identifying groups of similarly vulnerable places and applies it to empirically derive a typology of communities at risk from coastal flooding.

2. Indicator-based vulnerability analysis

Place-based indicators have been applied extensively in research and practice to operationalize concepts of vulnerability and contribute to evidence-based policy making for risk reduction. The idea that groups of people have unequal vulnerability – that interacting factors such as poverty and access to political power differentially influence their capacity to anticipate, cope with, resist and recover from the impacts of hazards – is well established in the literature (Wisner, Blaikie, Cannon, & Davis, 2004). The concept extends to the differential vulnerability of places, whereby physical and socioeconomic attributes of communities exacerbate or ameliorate the potential impacts of natural hazard events (Cutter et al., 2008).

Indicator-based vulnerability analysis quantitatively represents and assesses important attributes of communities that contribute to their loss potential (Cutter, Boruff, & Shirley, 2003). Typical measures pertain to such aspects as population size, highly vulnerable socio-demographic groups, income, and building stock characteristics that represent what is at risk (exposure) and its susceptibility to loss (sensitivity). Similarly motivated studies of resilience analysis additionally incorporate indicators of communities' capacity to recover from disasters (e.g., Lam, Reams, Li, Li, & Mata, 2015). While the appropriate number and selection of indicators remains an area of debate (Stafford & Abramowitz, 2017), the suite commonly encompasses broad categories of the community's assets and capacities, referred to as capitals. These generally include social, economic, and built environment capitals; some frameworks variously include human, institutional, and/or natural capital (see Chang et al., 2015; Cutter, 2016).

Numerous studies have applied indicator-based approaches to assess the vulnerability of coastal locations and communities (Nguyen, Bonetti, Rogers, & Woodroffe, 2016). Some address coastal vulnerability generally (Frazier, Thompson, Dezzani, & Butsick, 2013) while others focus on vulnerability to specific hazards such as hurricanes and storm surge (Bjarnadottir, Li, & Stewart, 2011; Rygel, O'Sullivan, & Yarnal, 2006), tsunamis (Wood, Burton, & Cutter, 2010), marine oil spills (Santos, Carvalho, & Andrade, 2013), coastal erosion (McLaughlin & Cooper, 2010), loss of coastal wetlands due to urbanization (Huang, Li, Bai, and Cui, 2012), or coastal flooding and sea-level rise (Balica, Wright, & van der Meulen, 2012; Felsenstein & Lichter, 2014; Wu, Yarnal, & Fisher, 2002). Such applications draw attention to aspects of exposure particular to coastal hazard contexts, such as elevation and population in coastal zones. At the same time, they recognize the need to represent the many vulnerability attributes that are not coastally specific; for example, sensitivity attributes such as low income or elderly populations that are as relevant in extreme heat or earthquake events as in coastal floods.

The indicators-based approach to assessing vulnerability and resilience to hazards is popular largely because it produces findings that can be easily interpreted by policy makers, synthesizing complex information into a metric, or score, that can be relevant to policy decisions (Hinkel, 2011). Reducing the complexity of vulnerability to a quantitative measurement entails some limitations, however: indicators cannot fully capture the breadth, nuances, and interactions of factors that produce vulnerability (Adger, 2006; Barnett, Lambert, & Fry, 2008; Jones & Andrey, 2007; Rufat, 2013) or the dynamics of an evolving process (Cutter et al., 2008; Fekete, 2012; Mustafa, Ahmed, Saroch, & Bell, 2011). Recognizing that vulnerability is context-specific, some researchers have advocated incorporating input from people knowledgeable about local conditions in constructing indices that are locally relevant and meaningful to policy makers (Barnett et al., 2008; Frazier et al., 2013; Oulahen, Mortsch, Tang, & Harford, 2015).

While the preponderance of vulnerability indicator studies concerns relative vulnerability, recent studies have called for approaches with a different but related goal: discerning patterns, similarities, and differences in vulnerability (Chang et al., 2015; Cutter, Ash, & Emrich, 2016; Kok et al., 2016; Wood et al., 2015). Assessing relative vulnerability highlights places that may have "high" vulnerability, thereby supporting policy-makers in prioritizing localities for attention, allocating limited resources, and drawing attention to factors that cause people and places to be vulnerable. In contrast, similarity analysis identifies places that share vulnerability conditions. Results can support communities in seeking "peer" localities that may be confronting similar problems using similar strategies, regardless of whether or not they are considered to be highly vulnerable. The Hazard Vulnerability Similarity Index (HVSI) proposed by Chang et al. (2015) enables a one-to-many matching whereby an individual community can identify other similarly vulnerable places.

There remains a need to understand what types of coastal vulnerability exist and which are predominant. A typology of coastal communities can support higher levels of government in efficiently developing risk reduction guidelines that are more applicable to local contexts, and can facilitate establishing and augmenting networks of peer localities for knowledge exchange and advocacy. Cluster analysis, a family of statistical techniques for delineating groups of similar units, offers a well-established approach for developing a community typology. Researchers in applied geography have utilized cluster analysis to classify spatial units ranging from urban greenspaces (Kimpton, 2017) and urban neighborhoods (Delmelle, 2015) to fishing communities (Pollnac, Seara, Colburn, & Jepson, 2015) and vulnerable watersheds (Tran, O'Neill, & Smith, 2010). Applications are also emerging in the natural hazard and climate change fields, yielding typologies of highly vulnerable urban neighborhoods (Rufat, 2013; Stafford & Abramowitz, 2017), agricultural land vulnerability to climate change (Kok et al., 2016), and tsunami vulnerability (Wood et al., 2015). This paper applies cluster analysis methods to develop a typology of communities at risk of flooding and other coastal hazards.

3. Materials and methods

The methodological approach develops and demonstrates the value of a typology of coastal communities in three phases. A set of communities is first identified within the study region and characterized by a suite of hazard vulnerability indicators. Second, the communities are grouped according to their indicator profiles using cluster analysis, generating a typology of coastal communities in the region. The final phase addresses situations where new communities may wish to be matched to this established classification; for example, to access resources such as adaptation guidelines that have been tailored to different types of coastal communities. In this final phase, three new communities from outside the original set are matched to the typology from phase 2 using an index of similarity.

3.1. Study area

The methodological approach is demonstrated through a case study application in the Pacific coastal region of Canada. Specifically, the analysis includes the 50 largest coastal communities along the Strait of Georgia, the most populated region of the west coast (Fig. 1). These communities face similar coastal hazards related to climate change (e.g., storm surges, coastal erosion, and sea-level rise) and other marine risks such as tsunamis, shipping accidents, oil spills and contamination.

From a vulnerability perspective, the 50 communities exhibit considerable diversity in their geographic and socioeconomic attributes. Communities here consist of municipalities or areas deemed equivalent to municipalities for statistical reporting purposes (i.e., census