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Assessing spatial vulnerability from rapid urbanization to inform coastal urban regional planning

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A B S T R A C T

This study delves into the development of a Geographic Information System (GIS) based vulnerability assessment tool for assessing coastal vulnerability and making prescriptive recommendations on urban planning in coastal regions at a local level. The framework of “exposure-sensitivity-resilience” (ESR) is not only applied, but also improved and refined to take into account a suite of social-ecological indicators. The results demonstrate that vulnerability was not evenly distributed across Haikou's coastal zones, which may be linked to the different stages of ongoing urban planning for coastal Haikou. For the case study areas, vulnerability tends to increase with higher levels of urbanization, but may decrease once the speed of urban expansion is under control. The most vulnerable area is the main city zone where urban residents are concentrated and a developed transportation network exists. Our study contributes to the development of a general methodology to assess vulnerability in rapid urbanization and to apply it to coastal cities around the world.

1. Introduction

Vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change, as well as from the absence of the capacity to adapt (Adger, 2006). It is dynamic, spatially variable and scale dependent (Srinivasan et al., 2013). Large changes in climate and land use cause a decreasing supply of ecosystem services, resulting in increased vulnerability (Schröter et al., 2005). Coastal areas are densely populated and vulnerable to impacts of climate change and sea-level rise (SLR) (Yoo et al., 2011; Kumar et al., 2010; Sales Jr., 2009; Torresan et al., 2008; Peng et al., 2005). Temmerman and Kirwan (2015) found coastal megacities had been particularly vulnerable to encounter nature hazards, such as SLR and hurricanes.

Several scholars have introduced methods to measure coastal vulnerability. For example, Licuanan et al. (2015) put forward Integrated Coastal Sensitivity, Exposure, and Adaptive Capacity vulnerability (I–C-SEA Change) tool to identify the impacts of climate change and human activity in coastal areas. Similarly, Alexandrakis and Poulos (2014) presented the Beach Vulnerability Index (BVI); a new index that depends on the numerical approximation of indicators that correspond to the mechanisms related to the processes that control beach evolution. Arkema et al. (2013) used SLR scenarios to calculate a hazard index for the United States coastline and the group assessed the combined risk to habitats from multiple ocean users (Arkema et al., 2014). Dwarakish et al. (2009) calculated a coastal vulnerability index to identify areas vulnerable to inundation due to future SLR, and land loss due to coastal erosion in the west coast of India. Adopting a participatory research approach, Sales Jr. (2009) examined the vulnerability of socioeconomic groups among the coastal population, along with their adaptation strategies and adaptive capacity to cope with the impacts of climate variability/extremes and SLR on urban coastal communities and ecosystems in Philippines. Das (2012) studied 262 villages lying within 10 km of the coastline in one of the most cyclone-prone districts of India and estimated the probability of expected human fatality in these villages due to severe weather. As these studies demonstrate, a coordinated expansion of monitoring

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efforts on coastal wetland vulnerability to accelerated SLR is important to inform coastal climate change adaptation policy (Webb et al., 2013). If current trends in climate change and population density continue global water resources will be vulnerable in the future (Vörösmarty et al., 2000). Areas with high probabilities of urban expansion will be mainly located in coastal regions by 2030 (Seto et al., 2012). Arkema et al. (2015) claimed human activities would affect the flow of benefits in coastal management plans.

Key vulnerabilities include social, economic and political dimensions in addition to natural and environmental dimensions (Becken et al., 2014). Human society affects environmental change but is also vulnerable to these changes (Armas and Gavris, 2013). Studies have used many different methods to measure such complex change and vulnerabilities. Newton and Weichselgartner (2014) used a Driver-Pressure-State-Impact-Response (DPSIR) analysis to find societal pathways and responses in hotspots of coastal vulnerability. Lepy et al. (2014) evaluated this approach for assessing local vulnerability and adaptation of tourism to the challenges of climate change in two tourism municipalities of Northern Finland. Armas and Gavris (2013) used spatial multi-criteria analysis to assess social vulnerability - an urban process that increased in a post-communist Bucharest, raising the concern that the population at risk lacks the capacity to cope with disasters. Pearsall (2009) employed a Vulnerability Scoping Diagram approach to identify components that contribute to vulnerabilities and perceived vulnerabilities in the local community from four neighborhoods with brownfield redevelopment activities in New York City. Rosello et al. (2009) proposed a scheme of vulnerability indicators within the human environment focused on different aetiological risks based on a theoretical revision of the social vulnerability concept. Fraser et al. (2003) conducted extensive research in a limited number of watersheds collecting household data on socio-economic pathways.

Vulnerability assessment due to SLR, extreme weather events, or natural hazards including tropical storms has been fully documented, but the roles played by human dimensions, such as rapid urbanization, Land Use and Cover Change (LUCC) dynamics or through various socio-economic factors (e.g. tourism) determining environmental vulnerability are rarely taken into account. Turner et al. (2003) presented a vulnerability framework for the assessment of coupled human-environment systems on the basis of exposure, sensitivity and resilience without quantitative analysis. While there is consensus that urbanization is one of the major trends of the 21st century in developing countries, there is debate as to whether urbanization will increase or decrease vulnerability (Srinivasan et al., 2013). Coastal regions in China are undergoing rapid land use change, but little attention is paid to the implications of this change for vulnerability.

The objectives of this paper are: (1) to present an analytical framework and associated indicator system to assess spatial vulnerability in coastal areas based on Turner's framework (Turner et al., 2003), and (2) to integrate spatial management for coastal urban-ecosystem vulnerability assessments in conjunction with expert knowledge and multi-criteria analysis to aid planners and policy/decision makers, using a social-ecological system modeling approach. We are specific with respect to vulnerability to more general environmental stresses as a result of urbanization, and do not assess vulnerability due to SLR and typhoon hazards in this research.

2. Materials and method

2.1. Study area

According to China's first National New-type Urbanization Plan in 2014, over 12 million rural residents will become urban residents every year for the next few decades. The urban built-up land area in China has grown by 78.5% in the past decade - faster than its urban population, which grew by 46% (Bai et al., 2014). Rapid urbanization, rapid environmental degradation and related risks, along with the state of the natural environment of the coastal regions across China, are well documented (Li et al., 2010, 2014).

Hainan Island (a provincial level political jurisdiction) is the largest special economic zone in China. The development of "Hainan International Tourism Island" has had an important and demonstrated effect on the adjustment and optimization of the economic structure, and has transformed the development of coastal China (Gu and Wall, 2007). As the capital and most populous city in the Hainan province (Fig. 1), Haikou's population has risen from 331,000 in 1990 to 1,586,000 in 2010, according to the UN Habitat's State of the World's Cities 2012/2013. The population is expected to grow to 2,065,000 in 2025, a 524% increase since 1990. Urbanization accounted for 60% of the population in 2010 and is expected to increase to 80% by 2020 in Haikou. Haikou is also a key point in the establishment of Hainan International Tourism Island. The GDP of Haikou was 71.275 billion CNY in 2011, with tourist income totaling 8.302 billion CNY, making up 11.6% of total GDP.

Haikou urbanization is tourism-driven, characterized by a significant floating population and associated tourism activity infrastructure (Qian et al., 2012). However, early urban tourism development, which was not well regulated or managed, gradually destroyed the coastal environment and ecosystem resources on which tourism depends. For example the growing number of tourists visiting environmentally sensitive natural areas may have negatively affected coastal protection areas (Burak et al., 2004). According to the Regulations for Haikou Coastal Zone Management, the coastal zone of Haikou, shown in Fig. 1, is classified into three types: sandbank-lagoon coast, sandy coast and the muddy coast (Chen, 2010), and occupies the Dongzhaigang National Mangrove Nature Reserve. The Haikou coastline is about 136.23 km and the natural coastline accounts for about 74.7% or 101.7 km. In contrast, the artificial shoreline has a length of 34.5 km accounting for 25.3% of the entire city coastline and is mainly used for tourism, ports, etc. Accelerating economy and rapid urbanization has pushed city development towards a highly vulnerable status that includes near-shore seawater degradation, coastal erosion and susceptibility to natural disasters such as typhoons.

2.2. Indicator system

Utilizing the Turner Vulnerability-Assessment framework, this paper applies 9 indicators to analyze the vulnerability of the coastal zone of Haikou in terms of exposure, sensitivity and resilience. The study includes quantification of: the Exposure Indicator (EI), Sensitivity Indicator (SI) and Resilience Indicator (RI). Respectively, EI reflects the extent of human activities, and includes data on; land urbanization, population urbanization and tourism development. SI reflects the conditions of the natural and geographical environments, in addition to traffic accessibility levels and includes data for; digital elevation modeling (DEM), geological hazards and traffic conditions. RI represents the resilience of the ecosystem, which includes; natural habitats, coastal-type data and services. In quantifying the EI, SI and RI, a Vulnerability Indicator (VI) can be assessed and compared among different communities (Table 1).

2.3. Data preprocessing

The quantification and the algorithm for the evaluation index system is shown in Table 2.