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A comprehensive risk analysis of coastal zones in China

Guanghui Wang [a,b,c], Yijun Liu [a,b], Hongbing Wang [a,b,*], Xueying Wang [d]

[a] Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, China
[b] CAS Center for Interdisciplinary Studies of Social and Natural Sciences, Beijing 100190, China
[c] University of Chinese Academy of Sciences, Beijing 100190, China
[d] Beijing Foreign Studies University, Beijing 100089, China

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ABSTRACT

Although coastal zones occupy an important position in the world development, they face high risks and vulnerability to natural disasters because of their special locations and their high population density. In order to estimate their capability for crisis-response, various models have been established. However, those studies mainly focused on natural factors or conditions, which could not reflect the social vulnerability and regional disparities of coastal zones. Drawing lessons from the experiences of the United Nations Environment Programme (UNEP), this paper presents a comprehensive assessment strategy based on the mechanism of Risk Matrix Approach (RMA), which includes two aspects that are further composed of five second-class indicators. The first aspect, the probability phase, consists of indicators of economic conditions, social development, and living standards, while the second one, the severity phase, is comprised of geographic exposure and natural disasters. After weighing all of the above indicators by applying the Analytic Hierarchy Process (AHP) and Delphi Method, the paper uses the comprehensive assessment strategy to analyze the risk indices of 50 coastal cities in China. The analytical results are presented in ESRI ArcGis10.1, which generates six different risk maps covering the aspects of economy, society, life, environment, disasters, and an overall assessment of the five areas. Furthermore, the study also investigates the spatial pattern of these risk maps, with detailed discussion and analysis of different risks in coastal cities.

1. Introduction

Together with rapid urbanization, urban crises and hazards have seriously jeopardized the coordinative development of society, economy and eco-environment. Due to the fast urbanization process, coastal zones have been densely populated and economically developed. They harbor more than 60% of the global population (UNEP, 2009), with a third of the coastal cities having a population of over 1 million (UNFPA, 2009). In consideration of these factors, coastal zones will suffer much more when confronted with hazards, such as global warming, sea level rise, storm surges, increased settlements, and land subsidence. Mitigating the effects of potential natural disasters requires detailed and extensive knowledge on crisis management in coastal zones and the literature survey indicates that various analytical techniques can be applied to measure the effects caused by hazards.

A large effort has been devoted to studying coastal disasters at both the global and regional scales. The global scale research mainly analyzed the influences and threats of coastal hazards from a global perspective. For example, Dasgupta et al. (2011) analyzed the exposure level of vulnerable elements in developing countries, when confronted with heightened storm surges. Hinkel et al. (2010) evaluated the risk of climate change to the European Union's adaptation in the 21st century. Menon et al. (2010) analyzed the effect of sea level rise on global biodiversity. At the regional scale, previous studies mainly focused on a specific area. Kleinosky et al. (2007), Peacock et al. (2005), Parkinson and McCue (2011), and Saha et al. (2011) assessed the storm-surge flooding changes and its regional vulnerability in South Florida, USA. Vinchon et al. (2009) and Deboudt (2010) investigated coastal risk management in France. Kumar (2006) and Dwarakish et al. (2009) explored the potential vulnerability implications of climate change around the southwest coastal zones in India. Furthermore, Paniconi et al. (2001), Snoussi et al. (2008), Sales (2009), and Bhuiyan and Dutta (2012) evaluated the vulnerability and adaptation of the coastal zones in Tunisia, Morocco, Philippines and Bangladesh, respectively. Although the above studies have covered most of coastal

* Corresponding author. Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, China.
E-mail address: hbwang82@163.com (H. Wang).

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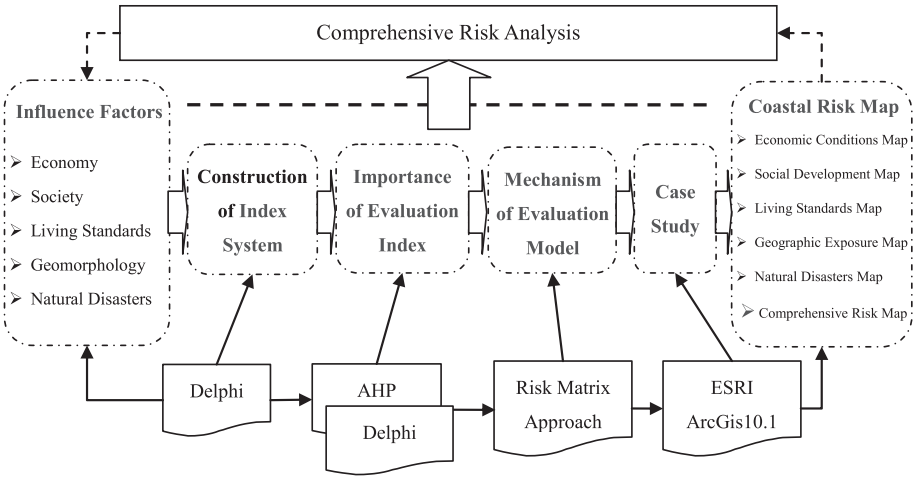

Fig. 1. Rationale and methodology of the work.

zones, there is little related research in China, a country with a mainland coastline of more than 18,000 km.

An overall rationale and methods and GIS (Geographic Information System) tools can be effectively used to assess coastal risk and vulnerability. For example, Chu-Agor et al. (2011) and Purvis et al. (2008) explored the risks of coastal zones by using uncertainty analyses and probabilistic methodology, respectively. Meliadou et al. (2012) used fuzzy cognitive mapping approach to analyze coastal vulnerability. Mahendra et al. (2011), Gambolati and Teatini (2002) and El-Raey et al. (1999) evaluated the risk of coastal zones by applying remote sensing and geospatial techniques. Among all these methods and tools, the evaluation index and GIS are the primary tools. Carrasco et al. (2012), Yasuhara et al. (2012) and Wong et al. (2009) used an environment index to assess and forecast the coastal risk. Bush et al. (1999) and Navas et al. (2012) mainly applied geo-indicators for the rapid assessment of coastal-hazard risks. Darwin and Tol (2001) estimated the economic effect of climate change by using the index of direct cost and equivalent variations. In the practical field, the UNEP developed a global index for the measurement of coastal risk and vulnerability, which includes population density (DE), probability of natural disaster incidents (ND), forests cover (FC), geographic exposure (GE) and human development (HD) (UNEP/Earthprint, 2006). The UNISDR (United Nations International Strategy for Disaster Reduction) also designed a set of coastal vulnerability indices (physical, environmental, and economical aspects) from the perspective of natural disaster reduction (ESCAP/UNISDR, 2012). While most of these methods or indices mainly focus on natural factors, they cannot reflect the social vulnerability and regional disparities of coastal zones. Although there have been some social indices for vulnerability assessment in the practical field, the importance of each index is not well-defined.

Hence, there is an urgent requirement for a better quantitative assessment method to evaluate the comprehensive risk or vulnerability of coastal zones in response to natural disasters. Considering these situations, this paper aims to build a comprehensive assessment strategy with the model of vulnerability assessment and multi-risk matrix. The paper is then organized as follows: Section 2 builds a set of scientific, complete and quantitative risk assessment model and index system, which include both natural and social factors. Section 3 presents a series of risk maps of the 50 coastal cities in China and discusses the spatial pattern of these risks. Section 4 concludes the work and provides future implications.

2. Comprehensive risk analysis model and its index system

All the above works propose the evaluation index system based on geographic exposure, natural disaster incidents and the Human Development Index. These results mainly focus on a certain risk in coastal zones (Pelling et al., 2004; Wisner et al., 2007). Therefore, it is necessary to set up an optimal index formula suitable for multi-disaster evaluation, especially for the man-made vulnerability after natural disasters. Considering the effect of economic and social development on coastal risks, this section proposes a comprehensive risk analysis strategy for coastal zones.

2.1. Rationale and methodology

The objective of the work is to construct a comprehensive risk analysis model for coastal zones, which should consider various influencing factors of coastal risks at the same time. In Fig. 1, these factors are categorized into economy, society, living standard, geomorphology and coastal disasters. First, the work builds an index system for risk analysis based on the above factors. Second, methods, such as Analytic Hierarchy Process (AHP) and Delphi, are used to calculate the importance and weight of the evaluation index. Then, the comprehensive risk analysis model is proposed based on the mechanism of RMA. Lastly, the work takes 50 coastal cities in China to test the model above.

2.2. Evaluation index system and its weight

(1) Construction of the index system

Based on the principles of usefulness, comprehensiveness, scientific validity, and applicability, this study establishes a comprehensive risk analysis system for coastal zones, which has three hierarchies containing the decision goal, the evaluation criteria, and the detailed factors under each criterion (Fig. 2). Every hierarchy is comprised of some related indicators, which are determined by the method of Delphi. After several rounds of questionnaire survey, we achieved the above indicators. There were 20 experts who participated in the Delphi experiment, including five researchers, five government officials, and ten coastal residents. The researchers include professors and PhD candidates with backgrounds of economics, sociology, management, geography and meteorology. The five government officials come from the administration departments on civil affairs, commerce, finance, ocean and