



Research article

Ecological vulnerability assessment for ecological conservation and environmental management

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ABSTRACT

Identifying ecological vulnerable regions is a significant aspect in ecological conservation and environmental management. This paper presents a first attempt to provide a prototype framework that can assess ecological vulnerability and evaluate potential impacts of natural, social, economic, environmental pollution, and human health elements on ecological vulnerability with integrating spatial analysis of Geographic Information System (GIS) method and multi-criteria decision analysis (MCDA). A general ecological vulnerability index was constructed to describe the vulnerability status in an ecological hot-spot of China. The assessment results of this study confirm the poor ecological vulnerability in China that only 1.32% of the China's population lives in not vulnerable ecosystem. A very high percentage (98.68%) of Chinese with 1.34 billion people lives in vulnerable and highly vulnerable area. This situation is mainly caused by increasing population pressure, exhausted nature resources, extensive economic growth, severe environmental pollution, insufficient environmental protection investment, and accelerating population aging. The spatial comparison indicates that spatial disparity existed in China with the central and northwestern provinces showing higher ecological vulnerability than the northeastern and southern provinces. The results of ecological vulnerability assessment can support effective guidance for mid- or long-term ecologic management. The developed framework can be replicated at different spatial and temporal scales using context-specific datasets to support ecological managers and government with decision-making. With available robust climate change models, future research might incorporate climate change into the ecological vulnerability framework.

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1. Introduction

The global and regional eco-system is experiencing unprecedented press and deterioration due to climate change, economy development and humankind activities (Hua et al., 2015; Mitchell et al., 2015; Farley and Voinov, 2016; Virapongse et al., 2016; Blanco et al., 2017; Liang et al., 2017a, 2017b; Chen et al., 2016; Li et al., 2017; He et al., 2017; Chen et al., 2017). Ecological vulnerability assessment is a useful tool to help decision makers understand the various impacts of natural and factitious elements on ecosystem. Under this circumstance, evaluating the ecological vulnerability is necessary to make implications for ecological conservation and environmental management.

Vulnerability is an indicator that integrates multiple multi-dimensional and multivariate attributes (Gonzalez et al., 2010; Chuvieco et al., 2014; Maru et al., 2014; Sugden et al., 2014; Absar and Preston, 2015; Rogers and Xue, 2015; Buotte et al., 2016; Rebolledo et al., 2016; Stevenazzi et al., 2017). As the concept of ecological vulnerability is yet to be fully expounded, the development of vulnerability indices should be conducted at smaller scales and must be context-specific (Heltberg et al., 2009; Sietz et al., 2011; Schwarz et al., 2011; Tubi et al., 2012; Beroya-Eitner, 2016). Therefore, it's a challenge to identify those indicators that can capture ecological vulnerability attribute from the diverse and often incommensurate data. Compared to ecological vulnerability assessment, the vulnerability assessment of ecosystem services is more common. For example, Qiu et al. (2015) assessed the vulnerability of ecosystem services driven by urbanization in China with considering of 16 ecological and socioeconomic variables within an Exposure-Sensitivity-Capacity framework. But it's obvious that vulnerability of ecosystem itself is different with that

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of ecosystem services. Shen et al. (2016) employed a vulnerability paradigm that contained natural, human, economic, and social elements to assess the vulnerability of four ecosystem receptors (human health, groundwater, surface water, and atmospheric environment) separately in the case study of Beijing, China, but not with an integrated indicator that can straightly show the general ecological vulnerability. Wu et al. (2007) applied an assessment method that considered net primary productivity (NPP), length of growing season, and aridity index as assessment indicators to evaluate the impact of climate change on eco-environment in China under the B2 climate scenario from Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000) of Intergovernmental Panel on Climate Change (IPCC). However, impacts of social and human activity on ecosystem vulnerability were not taken into account in this method. Overall, few studies have focused on evaluating the vulnerability of eco-environment itself that simultaneously considers natural, social, economic, environmental pollution, and human health elements in an ecological vulnerability assessment framework.

As the largest developing country in the world, the eco-environment problem in China is not only our country's focus, but also the hot topic in the worldwide. China has been experiencing rapid economy growth and urbanization with average annual growth rate of 9% in Gross domestic product (GDP) in recent 20 years. However, China's economy has shown uneven regional growth that the coastal regions of eastern China represent more rapid economic growth than that in the other regions. Non-synchronized development of private firms and industrial structure cause the regional disparity. In 2013, China became the second largest global economy according to purchasing power parity and GDP. The urbanization rate has increased into 56.1% in 2015 from 10.64% of 1949. However, the rapid economy growth and urbanization lead to severe ecological problems, such as atmospheric pollution, water contamination, waste pollution, forest deficit, water and soil loss, desertification, and accelerated extinction of biologic species. These ecological problems have seriously affected human health and economic development. The estimation from Chinese Academy of Sciences (CAS) indicated that the economic loss from environmental pollution and ecological destruction in China occupies 15% of the GDP, but the GDP growth is only 7%. This situation indicates that ecological problems may seriously restrict sustainable development and economic development achievements. Therefore, it's an urgent and indispensable task to evaluate ecological vulnerability in China. However, little research has focused on ecological vulnerability assessment in China at a provincial level because of construction difficulty of ecological vulnerability assessment frame and data limits.

The purpose of this paper is to integrate natural, social, economic, environmental pollution, and human health elements within an ecological vulnerability assessment framework that combines spatial analysis of Geographic Information System (GIS) method and multi-criteria decision analysis (MCDA). 15 sub-parameters reflected natural and anthropogenic elements are selected to capture ecological vulnerability attribute and then divided into four groups: ecological situations, ecological infrastructure, environmental situations, and human health. Therefore, a general ecological vulnerability index was constructed to describe the vulnerability status in an ecological hotspot of China. The constructed ecological vulnerability assessment framework will be expected to answer the following three questions: 1) how's the general ecological vulnerability in China? 2) Which provinces in China are the most vulnerable to the increasing ecological problems and anthropogenic activities? And 3) what effective environmental management and protection implications are demanded to sustain and improve the eco-environment capacity?

2. Methods and data source

Ecological vulnerability can be defined as 'the ability of ecosystems to absorb changes of state variables, driving variables, and parameters, and still persist'. It is affected by internal and external factors. The developed ecological vulnerability assessment methodology in this paper is proposed by aggregating the MCDA and spatial analysis of GIS. More specifically, the MCDA method can manage data from multiple sources and determine the weight of each attribute. The GIS is applied for spatial analysis and achieving general ecological vulnerability map. There are five steps in the ecological vulnerability assessment framework, as shown in Fig. 1:

- (1) indices selection and description;
- (2) ecological vulnerability attributes normalization;
- (3) weights determination by MCDA;
- (4) integration of general ecological vulnerability;
- (5) general ecological vulnerability map drawing by GIS.

2.1. Indices selection and description

Ecological vulnerability assessment is a complicated process. For now, there is no international recognized standard or rule to stipulate how many and what parameters should be selected to capture ecological vulnerability attribute. In order to select the evaluated indices with the smallest scale and the most representativeness, 15 representative indices reflected natural and anthropogenic elements are selected and divided into four groups: ecological situations, ecological infrastructure, environmental situations, and human health. The definitions and data sources of the 15 indices are represented in Appendix A.

2.2. Ecological vulnerability attributes normalization

To make these 15 indices comparable, the original data are normalized into a unified dimension, in a range from 0 to 1. This process is accomplished according to the class boundaries and normalization scores shown in Appendix A. The selection of the indices' classes and matching normalization scores are supported by Chenery structural transformation model (Chenery and Syrquin, 1975), the world's population distribution, Falkenmark Water Stress Indicator (Falkenmark et al., 1989), Technical Criterion for Ecosystem Status Evaluation (HJ 192-2015) (MEP PRC, 2015a,b), Environmental Quality Standard for Surface Water (MEP PRC, 2011), Ambient Air Quality Standards (MEP PRC, 2012), and 5 experts.

2.3. Weights determination

MCDA is a multi-criteria decision making tool to decompose a problem into a hierarchical structure. It has been widely applied in environmental risk assessment (Topuz and van Gestel, 2016), ecological impact assessment (Liu et al., 2015), sustainable development planning (Quaddus and Siddique, 2001), soil characterization (López et al., 2008), regional management of species resilience (Fuentes et al., 2013), regional climate change impact (Yin and Cohen, 1994), household vulnerability assessment (Eakin and Bojórquez-Tapia, 2008), groundwater management (Ren et al., 2016), atmospheric vulnerability assessment (Zhang et al., 2016), and many other fields. Analytical hierarchy process (AHP) is one of the most widely used MCDA tool. In our developed ecological vulnerability assessment, the AHP technique is applied to determine weights of the selected indices. This part contains six steps as following (Saaty, 1980; Saaty and Vargas, 2001; Nguyen et al., 2016):

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