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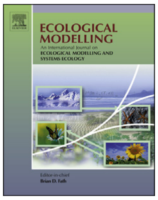

Urban ecological security assessment for cities in the Beijing–Tianjin–Hebei metropolitan region based on fuzzy and entropy methods

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ABSTRACT

Based on the pressure–state–response conceptual model, we constructed the urban ecological security evaluation index system for 13 cities in the Beijing–Tianjin–Hebei metropolitan region from 2003 to 2014, where integrated development has occurred up to the national strategic level. The entropy-weight method was used to calculate the index weights to eliminate subjectivity. After the perfection and detailing of the increased half-ladder membership function and the confirmation of the membership standard of urban ecological security evaluation, the fuzzy synthetic evaluation method was used to calculate, analyze and evaluate the ranks of urban ecological security from 2003 to 2012. The overall regional ecological security of the Beijing–Tianjin–Hebei metropolitan region increased during those 10 years. However, as expected for the obvious increase in the ecological state security level, neither the ecological pressure security nor the response security level significantly changed. In addition, urban social and economic indicators contributed more to the ecological security assessment than did the natural resource indicators and environmental indicators.

1. Introduction

Compared to a natural ecosystem, an urban ecosystem is characterized by high material and energy consumptions, high pollution and low natural resources, making it vulnerable and instable (Jiang and Chen, 2011; Liu et al., 2011b). There is no consensus on the concept of urban ecological security, and different connotations and denotations are derived from different dimensions of this concept (Gong et al., 2009; Tian and Gang, 2012). Badami and Ramankutty (2014) believed that, as urban agriculture and food security have an active relationship with food and nutrition security, income generation, and poverty alleviation, they are two key contents in the urban ecological security concept. Paton et al. (2014) recognized urban water supplement as one important aspect of urban security due to both its increased complexity and increased uncertainty under climate change. Jovanovic et al. (2010) suggested more attention be given to the energy system in an urban environment due to its complex structure with different types of resources and plenty of supplier and consumers. In addition, some researchers believe that urban ecological security should consider more social and economic factors (Michael et al., 2014). Ecological security means the absence of threats to human life, health, ease, basic rights, life ensure sources, necessary resources, and social sequence and the capability to acclimate environmental changes (Xiao et al., 2002). Combined with domestic and foreign academic viewpoints and studies on ecological security, the author believes that urban ecological security refers to the ecological factors and conditions in the natural-social-economic compound ecological system being able to support the sustainable development of the city. In addition, this concept has dynamic and relative connotations (Jia et al., 2004; Wang et al., 2011). As important as national defense security, economic security and food security, ecological security is the cornerstone and important component to national and regional security and development (Jia et al., 2004).

Related studies on ecological security have increased in recent years, mainly related to the connotation of the concept, the construction and management of regional ecological security, the strategic status and significance of ecological security and the monitoring technology and evaluation methods (e.g., index system and evaluation standard) of ecological security, etc. (Banos-González et al., 2014; Jiang and Chen, 2011; Li et al., 2010). Some scholars have performed exploratory research to evaluate ecological security. Although different methods have different foci, most of these

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Table 1
Ecological security evaluation index of the BTH region.

Object layer	Project layer	Index layer	Unit	Impact
Integrated ecological security evaluation (ES)	Pressure layer (*P*)	*P*1: domestic water-consumption per capita	m^3/capita	–
		*P*2: domestic electric consumption per capita	Kw h/capita	–
		*P*3: public green areas per capita	m^2/capita	+
		*P*4: industrial SO_2 emissions intensity	kg/10,000 RMB	–
		*P*5: road pavement area per capita	m^2/capita	+
		*P*6: urban population density	km^2/capita	–
	State layer (*S*)	*S*1: built-up area greening coverage	%	+
		*S*2: construction land proportion in municipal district	%	–
		*S*3: natural population growth rate	‰	–
		*S*4: per capita GDP	RMB/capita	+
		*S*5: per capita total investment in fixed assets	RMB/capita	+
		*S*6: announced unemployment rate	%	–
	Response layer (*R*)	*R*1: industrial solid waste utilization rate	%	+
		*R*2: sewage centralized treatment rate	%	+
		*R*3: tertiary industry proportion	%	+
		*R*4: proportion of fund for science & education in GDP	%	+
		*R*5: number of beds in health care institutions	Unit per 10,000 capital	+
		*R*6: number of higher education students	Unit per 10,000 capital	+

methods are based on the pressure–state–response model (PSR) (Hua et al., 2011; Pei et al., 2010; Zhang et al., 2012). The basic procedures of the PSR are index selection, weight assignment, index system establishment and status value calculation. However, there is still no complete ecological security evaluation index system, evaluation standard, quantitative index or corresponding evaluation model (Li et al., 2014b; Tian and Gang, 2012). Few studies of urban ecological security have been non-PSR-based, such as the case study of Li and Xu (2010) with an ecological network analysis method and Gong et al. (2009)'s study using the cellular automata method. Both of these studies used Guangzhou, China, as their study cases. In addition, Li et al. (2014a) analyzed the ecological security of three regions in Inner Mongolia, China, with an ecological footprint index system. Kang and Xu (2010) discussed the feasibility of using the spatial-temporal balanced ecological carrying capacity to assess the ecological security and its regulation. These studies undoubtedly increase our understanding on ecological security; however, subjectivity and lack of objectivity in the process of weight determination are still problems. In addition, the calculation method is quantitative, making it unable to fully represent the fuzziness nature of ecological security (Chen et al., 2014; Jiang, 2011; Shen et al., 2015).

Based on the above considerations, this paper combined the PSR method, the fuzzy logic model and the entropy weight method in an empirical study for feasible urban ecological security evaluation modeling. The PSR method was used to establish an evaluation index system regarding the essence of ecological security. The Entropy method was used in the weighing assignment process to verify the objectivity of this modeling. The fuzzy method was used for the quantitative analysis to determine the fuzziness of urban ecological security. Finally, this method was used to evaluate the ecological security of the Beijing–Tianjin–Hebei (BTH) region from 2003 to 2012. BTH is famous for its strategic position as the area surrounding the capital. This paper analyzed both the temporal and spatial dynamics in this area. Not only was the study case novel, but both the research issue and combined method were original. The results are interesting, and some recommendations are given at the end.

2. Method description

2.1. PSR conceptual model for urban eco-security index

Various methods have been used for ecological security evaluation: exposure-response method, integrated index number method, ecological capacity analysis and some ecological models (Wang and Cheng, 2003). After comparing the other methods, the authors recommended the pressure–state–response (PSR) concept model to establish the urban ecological security index due to its clear structure and logic. In addition, the analysis resulted in a PSR framework that can be easily understood and applied by decision makers in practice.

The concept of the environmental PSR index was proposed by Organization of Canadian Economic Cooperation and Development (OECD) and the United Nations Environment Program (UNEP) (Tong, 2000). The index system was established from three aspects that affect or are related to urban ecological security, i.e., the urban ecological pressure (the pressure from population growth and environmental resource assumption) the eco-environment state and the response (measures and policies that are adopted to solve eco-environmental issues) (Bai and Tang, 2010; Pei et al., 2010). With the help of expert consultation, frequency statistics and literatures investigation (Hua et al., 2011; Li et al., 2009; Theodoridou et al., 2012; Zhang et al., 2012), the evaluation index of the BTH region was established and is shown in Table 1. And the schematic of the cause-effect chain with indicators for the urban ecological security PSR framework was drawn in Fig. 1. In addition to the essence of the urban ecological security assessment, the choice of this index system was considered via other two aspects. The first aspect was the acceptability of the data. As there were changes in yearbooks during the study case period, some indicators did not have continuous data. The second aspect was the comparability of the data. Compared to scale indicators, percentage indicators are easily used in comparison between cities with different developed scales.

2.2. Entropy method for index weights

The key issue in evaluating ecological security (ES) from the 18 observed indicators was how to weigh each indicator with minimal subjectivity. The entropy-based weight method was used (Ludovisi, 2014; Zhang et al., 2006). In natural sciences, thermodynamic entropy is used to measure the disorder of a system. In social sciences, entropy information means the degree of uncertainty of a system. It is generally believed that the more entropy information one system has, the more balanced is its structure and the smaller is its difference (Chen et al., 2008; Han et al., 2014). From this perspective, the entropy information for each index was calculated, and smaller entropy means greater weight.

Using the calculation the weight of *P*1 as an example.

Define Pm'_{sid} as the observed Pm value for sample sid, and $sid = 1, 2, 3, \ldots, n$; $m = 1, 2, 3, 4, 5, 6$. The numbers of samples is n, which is the same in Sm'_{sid}, Rm'_{sid}.

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