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An integrated approach for assessing the urban ecosystem health of megacities in China

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ABSTRACT

In 2014, China adjusted its “city categorization standard.” The newly defined megalopolises and metropolises are under unprecedented pressure from various eco-environmental problems, making them suitable representatives for exploring the state of urban ecosystem health. In this study, we establish a two-layer indicator system to assess the urban ecosystem health and choose 33 indicators grouped into social, economic, transportation, facility, land, and management subsystems, with the aim of correlating human activities with the structure, vigor, resilience, and health of the urban ecosystem. We integrate subjective and objective methods to determine weights at different levels through the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the analytic hierarchy process, and information entropy. In particular, we develop a spatial TOPSIS technique by introducing a Euclidean-distance-based weight to rank the health of the cities' ecosystem in terms of the spatial effects among these cities. The results reveal that megalopolises such as Beijing, Shanghai, and Guangzhou have superior social and economic subsystems, whereas other megacities have advantages in transportation, facility, land, and management subsystems. From 2005 to 2010, the gaps among these cities in terms of urban ecosystem health significantly reduced regardless of the weight determination method. Not all indicators involved can help realize a better urban ecosystem. Nevertheless, they provide a reference point for making specific regulations to control human activity and improve eco-environmental management.

1. Introduction

In 2014, China adjusted its “city categorization standard,” where the term “megalopolis” was appended and the original four-tiered category was changed to a five-level system (State Council, 2014). This new categorization was designed to adapt to the rapid urbanization and industrialization in megacities in China. Environmental degradation due to mass migration, traffic, and industrial advancement is rampant in these large cities (Fang, 2014). In the face of eco-environmental problems caused by urbanization, ecological perspectives and ad hoc solutions have emerged and matured, and the assessment of urban ecosystem health has become a powerful tool (Chen & Wang, 2014; Liu, Zhan, & Deng, 2005).

In definition, urban ecosystem health has evolved from the concept of natural ecosystem health, which has been integrated with urban characteristics. In fact, in urban ecosystems, people live in high densities and structures and infrastructure cover much of the land surface (Pickett et al., 2011). Urban ecosystems are also characterized by high material and energy consumptions, high pollution, and low natural resources, making them vulnerable and instable (Jiang & Chen, 2011; Liu et al., 2011). Thus, urban ecosystem health describes a state in which an urban ecosystem maintains its integrity and health to continue supplying eco-services to humans maintaining a healthy state (Xu & Xie, 2012). Similar concepts have also been proposed such as “urban ecological health,” “urban ecological security,” and “urban ecological carrying capacity” (Su, Fath, & Yang, 2010); the distinct feature of “urban ecosystem health” lies in its focus on the reasonable structure and integral, efficient function of the ecosystem from the perspective of ecology, but it also emphasizes that the urban ecosystem can maintain its eco-services and prevent damage to human health and socioeconomic health. This integrated subject combines the characteristics of ecosystems and services for humans. With this concept, holistic operations and the development potential of urban ecosystems can be assessed and thus be applied extensively in urban management to evaluate the status quo of the urban ecosystem, identify the limiting factors, identify key problems, optimize the scheme, and guide ecological regulation (Su, Yang, & Chen, 2012a).

In the past years, an increasing number of studies have been conducted on urban ecosystem health or related assessments, which can

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be generally categorized into three groups. The first group tends to design the assessment via "pressure-state-response" or "pressure-resilience" frameworks (Dizdaroglu, Yigitcanlar, & Dawes, 2010; Zhang, Ma, Zhan, & Chen, 2012). Attempts have been made to define the pressure and response from human activities; to describe the characteristics of the pattern, process, and service of ecosystems; and to distinguish the external performance and internal metabolic processes (Andersson et al., 2014; Ahern, 2013; Su, Fath, Yang, Chen, & Liu, 2013). In this process, both physical indicators (soil contamination, water pollution, and land-use/land cover) and socioeconomic indicators (population, economy, and management) are measured and categorized (Zhang, Yang, & Yu, 2006; Su et al., 2010). In the second group, land-use and land-cover change is embedded in the urban ecosystem health assessment. Essentially, land offers various services, such as food provision, energy, habitat, accessibility, species diversity, and recreation, and hence occupies an irreplaceable position in sustaining urban development (Chambers, Simmons, & Wackernagel, 2014; Wackernagel et al., 2004). In this sense, researchers have combined land-use structure with its service and function to diagnose the urban ecosystem health through empirical models and investigations (Yu et al., 2013). In the context of rapid urbanization as well as widespread urban sprawl and urban shrinkage, there is growing concern about maintaining the land ecosystem health to realize a balanced urban ecosystem (Großmann, Bontje, Haase, & Mykhnenko, 2013; Wu, Ye, Qi, & Zhang, 2013). The third group considers the urban ecosystem as an integration of the natural and artificial environment whose health is largely reflected in its supply of eco-services to humans as well as its ability to maintain their health (Xu & Xie, 2012). In this group, more holistic frameworks including the vigor, structure, function, and resilience of the urban ecosystem are proposed, which also highlight their spatiotemporal and multi-scale features (Su et al., 2012b). In fact, these proposed approaches have already been applied to typical cities such as Beijing, Shanghai, and Guangzhou as well as urban clusters such as the Pearl River Delta and Yangzi River Delta in China to diagnose the comprehensive health status and to determine the limiting factors of the urban ecosystem (Li et al., 2014; Su et al., 2013; Zhao & Chai, 2015).

In most cases, the common method for assessing urban ecosystem health incorporates an index system and weight determination for a final value that reflects the health status of each city. Previous research has attempted to combine the advancements made in natural ecosystem health assessment with the distinct features of urban areas. Measures of vigor, structure, resilience, service function, population health, and management have been integrated, whereas the link between these components and socioeconomic activities is still weak. The categorization of urban ecosystem health into subsystems directly associated with population, economy, facility, transportation, land, and management has still not been formulated. Weight determination has been largely flexible, where the two mainstream subjective and objective methods help determine contribution of each factor in empirical studies. The assessment of urban ecosystem health requires both methods when indicators are in a complex form, which can reduce information redundancy and subjective bias. In addition, past attempts of weight determination in city-related studies have neglected the spatial effects in most cases despite urban development being a typical spatiotemporal process.

In this study, we aimed to assess urban ecosystem health by establishing a two-level indicator system associating ecosystem health with socioeconomic development. The information entropy, Spatial Technique for Order Preference by Similarity to Ideal Solution (S-TOPSIS), and analytic hierarchy process (AHP) methods are used to determine the weights in the process. These approaches were applied to the newly categorized 13 megalopolises and metropolises to evaluate their status quo and facilitate future urban management.

2. Materials and methodology

2.1. Materials

Based on the new "city categorization standard" measured by the number of permanent residents, Beijing, Tianjin, Shanghai, Guangzhou, Chongqing, and Shenzhen have been categorized as the megalopolises and Chengdu, Wuhan, Nanjing, Foshan, Dongwan, Xian, Shenyang, Hangzhou, Harbin, and Hong Kong as the metropolises. For data consistency and availability, we chose the 13 cities presented in Fig. 1 and Table 1 for the assessment of urban ecosystem health. Among these 13 cities, Beijing and Hangzhou occupy the largest administrative area; Chongqing has the largest population with >33 million in 2013; and Beijing showed the highest gross domestic product (GDP) of 317.98 billion USD in 2013.

In the context of rapid urbanization, Beijing and Tianjin, as the capital city and a rapidly developing zone, have improved their natural resource utilization efficiency and contributed to the country's economy without compromising its own socioeconomic development (Wang & Yang, 2015; Yu, Li, Jia, & Li, 2015). Nanjing, Shanghai, and Hangzhou, as typical cities in the Yangtze River Delta, have strictly controlled the emission of pollutants to compensate for the eco-environmental damage due to rapid industrialization and urbanization in recent years (Li et al., 2014; Zhang & Gangopadhyay, 2015). Guangzhou and Foshan are two representative cities in the Pearl River Delta that have seen significant economic development and globalization, along with "low-carbon and green development" (Li, Liang, Cockerill, Gibbins, & Reiner, 2012; Yang & Li, 2013). The remaining cities are located in the middle, western, or northern regions of China, which slightly lag behind the southeastern cities in terms of development. However, with the national strategy of promoting the comprehensive development in these areas, these cities have witnessed rapid development, with a focus on building a resource-saving and environment-friendly society (Zhang & Bao, 2015). Overall, all of these cities are pioneers of urban and regional development but with various eco-environmental problems, and the respective governments have taken several measures to make improvements.

2.2. Methodology

2.2.1. Indicator system

Establishing an indicator system is one of the most important steps of urban ecosystem health assessment. In general, indicators are selected based on the principle of data acquisition, regionality, scientific, representative, objectivity, and early warning (Ting & Qi, 2012). The prerequisites for developing an indicator framework urban ecosystem health assessment are categorized into two aspects. First, indicators are organized in an integrated manner to strengthen the link between natural ecosystems and human ecosystems. Factors representing urban features are selected as comprehensively and systematically as possible. Second, indicators must generally be easy to understand and measure, as well as to regulate. The ultimate goal of urban ecological assessment is the provision of guidelines for urban management. Highly complex indicators can devalue the achievements in the assessment, whereas pragmatic indicators provide comprehensive results for further improvements to a city (Su et al., 2010).

Based on an extensive literature review, the urban ecosystem is decomposed into six components, and a two-tier indicator system is established in Table 2: (a) The social subsystem describes the growth and living conditions of the population. X1 (population density), X2 (proportion of nonagricultural population), X3 (unemployment rate), and X4 (natural population growth rate) are selected to indicate the social structure. (b) The economic subsystem refers to a city's vitality and economic level. X5 (per-capita GDP), X6 (proportion of the added value of the tertiary industry), X7 (proportion of the industrial added value), X8 (average industrial output), X9 (worker average wage), and