



Original Articles

Spatio-temporal investigation of the interactive relationship between urbanization and ecosystem services: Case study of the Jingjinji urban agglomeration, China

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ABSTRACT

Urbanization has altered landscape patterns and ecological functions, which has caused a decline in ecosystem services (ESS) and resulted in many ecological and environmental issues, particularly in areas that are undergoing rapid urbanization. A better understanding of the relationship between urbanization and ESS is important for future regional sustainability and relevant policy development. Most previous studies focus on the inter-relationship between urbanization and environment or refer to the effects of urbanization on ESS. The purpose of this study is to assess the relationship between urbanization and ESS in the Jingjinji (JJJ) urban agglomeration in northern China. The results revealed that with the rapid urbanization trend during the period 1996–2014, the value of ESS in the JJJ region increased by 4.63% because the increases in the forest, orchard and water areas greatly offset the decrease in ESS caused by urban sprawl, and both urbanization and ESS showed marked spatial variability. The temporal relationship between urbanization and ESS was represented by an inverse U-shaped curve; the peak was 0.7 for the urbanization index in 2009. Noticeably, there was no unanimous variation in the value of different ecosystem services types, and food production and waste treatment showed dramatic declines. There were negative spatial correlations between different levels of urbanization and ESS and particularly significant negative correlations among land, population urbanization and ESS. The central cities focused more on urbanization development than on ecological protection, whereas the Bashang Plateau and areas in the northern mountains featured unbalanced development and low levels of urbanization, and both the urbanization level and the ecosystem services value were low in the central southern plains. This indicated that, to realize urban ecological sustainability and develop sustainable regional paradigms, it is possible to strengthen socioeconomic urbanization while at the same time controlling the amount and distribution of land and population. The integration plan and action should be put forward to facilitate all measures taken in JJJ urban agglomeration planning and ecological conservation.

1. Introduction

The world is experiencing an unprecedented urbanization, the comprehensive development of economic, social, cultural and other factors, essentially a process of synthesis combining introvert agglomeration and extrovert extension (Wang et al., 2014a,b). Urbanization is characterized as a population shift from rural to urban, resulting in a gradual increase in the urban population density; it involves urban land expansion and transformation from a rural to an urban landscape, changes from agricultural to non-agricultural activities, urban economic expansion, changes in lifestyle and consumption behaviour and improved urban quality of life.

Ecosystem services (ESS) are benefits that people receive from the environment; specifically, provision (production of food and raw materials), regulation (of climate and hydrology), support (soil conservation and biodiversity maintenance) and cultural services (aesthetic landscape provision; MEA, 2003, 2005; Costanza et al., 1997). Although urbanization brings important benefits for economic, cultural and social development, urbanization and human activities have progressively altered natural processes, and this has transformed landscape structure and profoundly affected the interactions among the atmosphere, hydrosphere and biosphere; consequently, many of the ESS on which humanity relies for survival have been degraded (Li et al., 2013; Li et al., 2016). Currently, global ecological environmental changes due

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to urbanization are nearly ubiquitous, and these changes are projected to accelerate for decades to come (Qiu et al., 2015). How to reduce the effects of urbanization on the ecological environment and achieve sustainable development has become a matter of worldwide concern (Breuste and Qureshi, 2011; Breuste et al., 2013; Taylor and Hochuli, 2015), and challenges to understanding and solving urbanization-induced ecological problems continue to arise. Under such circumstances, determination of how urbanization interacts with ESS is necessary before priorities can be set for environmental management.

However, there are stresses and constraints on the interaction between urbanization and ESS, and their relationship is complex and interactive (Ai et al., 2016; Li et al., 2016). Increasing population density leads to high expenditure of multiple ecosystem goods and services and reduces the per capita value of ESS. Undoubtedly, the processes of urbanization have modified land cover and natural land use, resulting in local environmental changes that affect ESS. Although rapid economic development consumes natural resources and thereby intensifies the pressure on ESS, advanced economic performance could generate sufficient funds to protect and improve ESS. Along with changes in lifestyle and consumption habits, people often change their behaviour with respect to resource utilization and environmental protection. At the same time, people are generally eager to enjoy a higher level of cultural entertainment, which will encourage the improvement of ESS due to the greater general awareness of the environment (Yu, 2014). Moreover, urbanization generates a need for heterogeneous ESS across space and over time (Li et al., 2016).

ESS as an indicator of regional ecological environmental quality has attracted the interest of a wide variety of ecologists and geographers (Ahern et al., 2014; Costanza et al., 1997, 2014; Estoque and Murayama, 2013; Schmidt et al., 2014). Many studies have assessed the impact of urbanization on ESS (Alam et al., 2016; Li et al., 2016; Zhang et al., 2016; Peng et al., 2015; Wan et al., 2015). Such assessments help identify specific services that are declining because of urbanization. Some researchers explored the interrelationship between urbanization and environment, and this relationship could be expressed as a double-exponential curve combined with a logarithmic curve and an environmental Kuznets curve (Dinda, 2004; Nahman and Antrobus, 2005; Kijima et al., 2010). Few studies have explored the interactive relationship between urbanization and ESS. Furthermore, many existing studies that illustrate urbanization level using only a single parameter, such as GDP, population density, nighttime light or urban sprawl (Eigenbrod et al., 2011; Li et al., 2016), do not describe the comprehensive socioeconomic development. If the relationships between urbanization and ESS are not fully understood, ecosystems will quickly be degraded and urbanization will not achieve sustainable development (Zhan et al., 2012). It is necessary to establish an effective modelling approach to quantify multiple ESS and comprehensive urbanization, both explicitly and as regards their spatio-temporal relationship. Research on the relationship of ESS with urbanization will provide a new integrated approach to quantifying the ecological effects of urbanization.

The process of urbanization often leads to changes in the ESS in a certain region, and these changes are more significant in urban agglomerations with accelerated growth, particularly in population, spatial scale and economic scale, and huge demand of land, space and natural resources. However, how do ecosystems change with this rapid urbanization as time passes? Furthermore, are there any spatial differences in the impact of urbanization on ESS? To answer these two questions, the aim of the present study is to clarify how urbanization has interacted with ESS during the past decades at the urban-agglomeration scale. The main objectives are to present a comprehensive index system to evaluate the dynamic patterns of urbanization and ESS from 1996 to 2014 in the urban agglomeration region and to examine the spatial and temporal relationship between urbanization and ESS. Finally, suggestions on promoting a balance between ESS and urbanization and a sustainable future are discussed.

2. Materials and methods

2.1. Study area

The Jingjinji (JJJ) region, namely, Beijing city, Tianjin city and Hebei province, is the national capital region of China and the largest urban agglomeration in northern China. It is located in the eastern part of the North China Plain and the core of China's Bohai Sea area and includes 13 major cities, namely, Beijing, Tianjin, Shijiazhuang, Baoding, Langfang, Cangzhou, Qinhuangdao, Tangshan, Zhangjiakou, Chengde, Handan, Xingtai and Hengshui. Although it covers only 2.25% of Chinese territory (a total area of 216,000 km²), this region contains 8.08% of the national population (111 million), and it produced 10.45% of the total national GDP (6648 billion yuan) in 2014. Over the past three decades, the JJJ urban agglomeration has experienced rapid urbanization, with an annual growth rate of 1.43%, increasing from 38.86% in 1980 to 61.10% in 2014. In comparison, the average rate of increase in urbanization in China as a whole during that period was only 0.93%.

Inevitably, the continuous and rapid growth of urbanization has resulted in vast increases in the demand for ESS, competition for space and resources, and pressure on the environment. A number of studies have noted that the JJJ region has suffered a series of increasingly serious degradations in ecosystem functions and environmental problems generated by urbanization (Fang et al., 2016; Zhou et al., 2015). Like many other urban agglomerations around the world, JJJ faces the challenge of realizing sustainable development, which requires balancing the spatial heterogeneity of urbanization and ESS. Recently, a series of national strategic measures were enacted to promote the integration of the three jurisdictions into a single "mega city region". The economic, ecological and political dimensions of the unification plan in the JJJ region are considered, as are its implications as a resolution for environmental degradation, water shortages and uneven development. It is necessary to study the spatial and temporal heterogeneity of both urbanization and ecological services and their relationship in the JJJ urban agglomeration. This will provide a reference for exploring the optimization development mode with eco-environmental constraints and new patterns of coordinated development.

2.2. Data source and processing

Land use data were derived from survey data on land use change provided by Bureau of Land and Resources. Social-economic data were obtained from the *China Statistical Yearbook* (1996–2014), the *China City Statistical Yearbook* (1996–2014), the *Hebei Statistical Yearbook* (1996–2014), the *Beijing Statistical Yearbook* (1996–2014) and the *Tianjin Statistical Yearbook* (1996–2014). The data were standardized through formulas (1) and (2) to eliminate the influences of dimension, magnitude and positive and negative orientation.

$$\text{Positive indicator: } Z = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \quad (1)$$

$$\text{Negative indicator: } Z = \frac{X_{\max} - X}{X_{\max} - X_{\min}} \quad (2)$$

z is the standardized value of an individual indicator at the municipal level on a scale from 0 to 1, X is the actual value of the indicator and X_{\min} and X_{\max} indicate the minimum and maximum values of all indicators, respectively.

2.3. Selection of urbanization indicators and weights

Urbanization is a comprehensive development of economic, social, cultural and other factors, simply put, a complex system comprising various elements. The establishment of the index system is the core step in the evaluation of urbanization level. From the perspective of

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