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The evolution of landscape ecological security in Beijing under the influence of different policies in recent decades

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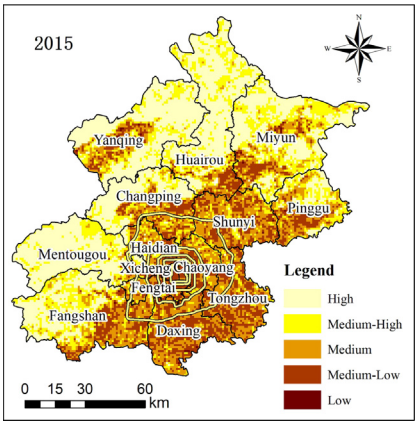
HIGHLIGHTS

- New remote sensing ecological security evaluation index for highly developed urban.
- Ecological security in urban and suburban of Beijing presented different trends.
- Ecological security in Beijing was closely related to the policy.
- Urban managers should consider ecological security when making policy.

GRAPHICAL ABSTRACT



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ABSTRACT

Urbanization is an important force driving the development of the social, economic, and ecological environments in urban China. As the capital of China, Beijing has experienced a shift in the development process from emphasizing economic development to emphasizing ecological livability in recent decades. During this period, the Olympic Games, real estate development, and environmentally friendly construction policies were major events that affected Beijing's urban ecosystem and its safety. Based on the Pressure–State–Response (P-S-R) framework model, this paper establishes an indicator system for assessing the ecological security of Beijing from 1995 to 2015. The indicators were generated through coupling of an ecological model with time-series multi-source remote sensing data such as night light images and Landsat ETM images. We assessed ecological security during different policy periods and developed an ecological security early warning system for Beijing. After the effects of the economic development policy and the bid for the Olympic Games from 1995 to 2005, the urban area of Beijing with falling ecological security continues to expand. From 2005 to 2010, due to the joint effect of 2008 Olympic venue construction, urban environmental remediation policies, and real estate policies, the overall safety level in the central city was better, but the suburbs showed the opposite trend. In 2010–2015, real estate developed explosively in Beijing, while environmentally friendly development became strongly emphasized and the economic status of the capital weakened. The ecological security of the main urban area began to improve

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significantly, but the outer urban area and suburban areas were greatly affected by real estate development and exhibited a clear decline in ecological security.

1. Introduction

The explosive growth of urban population has increased the impact on the environment. In addition, the rapid expansion of urban areas has led to problems such as fragmentation of urban landscapes, biodiversity reduction, urban heat island effects, and pollution, which have affected the service function of urban ecosystems and hindered the sustainable development of cities (Grimm et al., 2008; Poessel et al., 2014). As a representative of a highly developed city in China, Beijing has a relatively fragile ecosystem. The hosting of the Olympic Games promoted the greening process in Beijing and improvement of the urban ecological environment. However, there is still a large gap between the current status and the conditions required to become an "eco-city" (Liang et al., 2010; Yue et al., 2011). There are still three major problems that need to be resolved to improve the urban ecological environment in Beijing: insufficient urban green resources, unreasonable resource structure, and serious soil erosion in mountainous areas. Maintaining the ecological environment is still a difficult problem that besets the sustainable economic development of Beijing.

With acceleration of urbanization, there is an increasing need for coordination between urban social and economic development and the ecological and environmental benefits of the landscape, which will affect urban ecological security. Researchers have conducted valuable investigations of urban ecological security, and the results of such studies are becoming more abundant. In the 1940s, Quigley (Quigley et al., 2001) proposed that ecosystem management consists of four major components that are independent and complementary to each other: monitoring, evaluation, decision making, and implementation. Waltner-Toews (1996) proposed the need to evaluate the ecological resilience of ecosystems after being highly disturbed by humans. In recent years, the rapid development of geographic information systems/remote sensing (GIS/RS) technology has resulted in a more extensive range of its application. The use of these techniques has gradually improved the study of national or regional ecological security research. For example, based on GIS technology, Lee (Lee et al., 1999) proposed a close relationship exists between ecological value and landscape quality. Their results provide a reference value for urban ecological security management (Jiang, 2011; Li et al., 2011).

The Pressure–State–Response (P-S-R) framework model and its expansion are currently the most widely used indicator in the evaluation of ecological security (Li et al., 2010; Hua et al., 2011; Su et al., 2011). The most popular assessment methods include hierarchical clustering methods, the comprehensive index method, the analytic hierarchy process, and the landscape ecological security (LES) pattern. In recent years, with the rapid development of GIS/RS technology, the data acquired from ecological security research has exceeded that of previous regional surveys and economic statistics (Du et al., 2013; Lu et al., 2016). However, regarding the development of urban space, previous studies mainly evaluated the ecological security at a fixed point in time and did not consider the evolution of ecological security and its trends over time, which is now possible through dynamic assessments using remote sensing (Zhong et al., 2013). As a result, it is difficult to meet the increasing demand for assessments of the current levels of urban ecological security and urban sustainable development. There is an urgent need to determine how best to reveal the spatial characteristics and pattern of evolution of urban ecological security to enable dynamic assessments of urban ecological security and conduct an early warning analysis. However, it has proven difficult to couple an ecological security evaluation model with the urban spatial information obtained from remote sensing data to realize such dynamic assessments and conduct an analysis of early warning of urban ecological security.

Beijing has always been at the forefront of urban development because it is the capital of China. Therefore, evaluating the evolution of ecological security in Beijing has many forward-looking implications for urban spatial research throughout the country. Using the P-R-S evaluation model enhanced with remote sensing technology, we revealed the characteristics and pattern of evolution of ecological security in Beijing at a temporal and spatial scale under the influence of various policies, which enabled dynamic assessment of urban ecological security and establishment of an ecological security early warning assessment system.

2. Methods

2.1. Research area

Beijing, the Capital of the People's Republic of China (115°25′–117°30′E, 39°25′–40°51′N), is located at the North China Plain, near the meeting point of the Xishan and Yanshan mountain ranges. Beijing has 16 districts: Changping, Chaoyang, Daxing, Dongcheng, Fangshan, Fengtai, Haidian, Huairou, Mentougou, Miyun, Pinggu, Shijingshan, Shunyi, Tongzhou, Xicheng and Yanqing. Beijing City covers a total area of 16,808 km^2. Almost 62% of the total area is mountainous terrain, and the rest is plains. The terrain is high in the northwest and low in the southeast. The highest altitude is 2303 m. The climate of Beijing is a typical warm-temperate semi-humid continental monsoon climate. The water resource per capita (100 m^3) is one-eighth of China's average, lower than the global level and far below the international standard of water resources per capita.

Land use within Beijing has experienced a shift from agriculture to urban uses with the rapid development of the city. Urban land use has expanded from the center to the surrounding areas, which are accessed by the five ring roads (Second, Third, Fourth, Fifth, and Sixth rings). Urbanization in the suburban areas is becoming increasingly significant. Fig. 1 shows the location of Beijing.

2.2. Data sources

The data used in this study were obtained from the Landsat5 thematic mapper (TM), Landsat8 Operational Land Imager (OLI) remote sensing data, Defense Meteorological Satellite Program/Operational Linescane System nighttime light images, and Beijing nature reserve data. The Landsat5 TM and Landsat8 OLI data were used mainly to interpret four land use types in Beijing, and then to obtain the land use type and statistical data of each grid square. The nighttime light images mainly reflect the economic development level and population distribution of the region.

The Landsat data with 30 m spatial resolution was downloaded from the US Geological Survey Earth Resources Observation and Science Center (http://glovis.usgs.gov/index.shtml). The Landsat5 TM data imaging was obtained on September 16, 1995, August 26, 2005, and August 08, 2010 and the OLI data imaging on September 7, 2015. All data were Level 1T standard terrain correction products, obtained through radiation and geometric correction. A total of 12 images were used in this study. The data were then pretreated by atmospheric correction, projection conversion, image mosaicking, and cutting before use. A unified classification system was adopted with an object-oriented decision-tree classification method. The overall accuracy was >93%.