Ecological Indicators 82 (2017) 50–60

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Urbanization impact on landscape patterns in Beijing City, China: A spatial heterogeneity perspective

Huilei Li, Jian Peng*, Liu Yanxu, Hu Yi'na

College of Urban and Environmental Sciences, Peking University, Key Laboratory for Earth Surface Processes, Ministry of Education, Beijing 100871, China

ARTICLE INFO

Keywords:
Landscape metrics;Urbanization mode
GWR
Compact green city Beijing City, China

ABSTRACT

The temporal and spatial characteristics of landscape pattern change can reflect the spatial impact of urbanization on the ecological environment. Studying the relationship between urbanization and landscape patterns can provide supports for urban ecological management. Previous studies have examined the quantitative relationship between the social economy and landscape patterns of an entire region, but have not considered the spatial non-stability of this relationship. In this study, we characterized the landscape patterns in Beijing City, China during 2000 and 2010 using four landscape metrics, i.e. patch density (PD), edge density (ED), Shannon's diversity index (SHDI) and the aggregation index (AI). Geographically weighted regression (GWR) was employed to identify the spatial heterogeneity and evolution characteristics of the relationship between the urbanization of population density (POP), gross domestic production (GDP) and nighttime lighting (NTL), and landscape patterns. The evolution of urban landscape patterns indicated a decentralized, aggregated, and fragmented change from the downtown to the suburb and outer suburb. During the 10-year period, the average PD in the downtown increased by 100.6%, and the increase of AI in the suburb was the largest. The PD, ED and SHDI increased by different degrees in the outer suburb. The influences of different urbanization modes on landscape patterns were also different. Infilling mode made the landscape patterns more regular and integrated. The landscape was more broken and complicated under the edge-expanding mode, and the leapfrog mode made PD and SHDI increase slightly. In the relationship interpretation, GWR effectively identified the spatial heterogeneity, and improved the explanatory ability compared to ordinary least squares (OLS). The most intense response to urbanization was the forest landscape and the forest-cultivated land ecotone in the northwest of Beijing City, indicating that this region was ecologically fragile. The population density in the urbanization index had a direct effect on landscape patterns, while the PD affected by urbanization was greater than the shape, aggregation and diversity index. Affected by development policy, urban planning and other factors, the explanation degree of social economy to landscape patterns decreased in 2010. GWR is an effective method for quantifying the spatial differentiation characteristics of urbanization impacts on landscape patterns, which can provide more spatial information and decision criteria for the green development of a compact city.

1. Introduction

Issued by the Habitat III conference of cities on 20 October 2016, the New Urban Agenda pointed out by the middle of the century the world's urban population was expected to nearly double. This means that four of every five people will be living in towns or cities, making urbanization one of the most transformative trends in 21st century. Populations and socioeconomic activities are increasingly concentrated in cities, posing huge sustainability challenges in terms of housing, infrastructure, food security and natural resources management. Urbanization includes the changes of population, industrial structure and landscape types (Zhang and Su, 2016). The change of landscape types and proportions has been characterized by the conversion of ecological land such as forest land and grassland into agricultural land and construction land, and in some areas the agricultural land has been largely transformed into construction land (Weng, 2007; Liu et al., 2011). At the same time, the landscape patterns in rapidly urbanizing areas have presented a remarkable, highly fragmented feature. The single, continuous natural patches have become a complex, heterogeneous and discontinuous mosaics (Liu et al., 2014). The fragmented landscape hinders the spread of material and energy flow (Kreuter et al., 2001), and changes the regional energy, material and nutrient cycling process (McDonnell and Pickett, 1990). Thus, a fragmented landscape will affect the function and services of regional ecosystems

* Corresponding author.
E-mail address: jianpeng@urban.pku.edu.cn (J. Peng).

http://dx.doi.org/10.1016/j.ecolind.2017.06.032
Received 23 December 2016; Received in revised form 8 May 2017; Accepted 16 June 2017
Available online 27 June 2017

(Alberti, 2005; Estoque and Murayama, 2012; Peng et al., 2016b), resulting in a series of ecological and environmental problems (Li et al., 2010a; Jacobs, 2011), such as biodiversity loss, urban heat island effect, environmental pollution, soil erosion and so on (Wu, 2010; Schneiders et al., 2012; He et al., 2014; Zhou et al., 2014).

Understanding and solving the urbanization problems from the perspective of landscape pattern is one of the research hotpots in ecology and geography (Zhou et al., 2011; Shrestha et al., 2012; Estoque and Murayama, 2016). Landscape patterns can be quantified by landscape metrics, which are one of key tools to monitor, assess and manage the landscape (Li and Wu, 2004). The ecological consequences of urbanization can be understood by applying landscape metrics to describe and analyze the dynamic changes of regional landscape (Li et al., 2010b; Peng et al., 2016c; Schwoertzig et al., 2016). Landscape metrics have been extensively used for quantifying landscape patterns and their change. For example, Liu and Yang (2015) used landscape metrics to examine the size, pattern and nature of land use changes, demonstrating that landscape metrics could reveal the spatial characteristics and underlying processes of urban expansion. Kane et al. (2014) analyzed urban expansion based on landscape area, fragmentation, shape complexity and diversity. Su et al. (2014) analyzed the different responses of agricultural landscapes to urbanization by using urbanization indicators and landscape metrics. However, the changes of landscape patterns are spatially heterogeneous, and the evolution do not always move towards scattered and irregular forms. Different urban expansion modes and land use types will lead to different changes of landscape patterns.

Considerable studies have explored the relationship between landscape patterns and urbanization. The factors driving landscape change are mainly classified as biophysical and socioeconomic ones (Serra et al., 2008; Du et al., 2014; Maimaitijiang et al., 2015). Generally speaking, human activity can be reflected by socioeconomic factors, and nighttime light is the major factor in shaping the landscape. The soils, climate and other biophysical factors can also significantly affect the land use. However, because socioeconomic data are limited by statistical units, most of the studies have been conducted at city or county scale, and could not accurately reveal the spatial differentiation of the impact of socio-economic factors on landscape patterns (Ma et al., 2008). Many statistical models have been applied to describe the relationship between urbanization and landscape patterns, such as multiple regression and stepwise regression based on ordinary least squares (OLS) (Bagan and Yamagata, 2012). OLS model is a global parameter estimation technique (Zhang et al., 2009), based on two assumptions: (1) the model residuals do not exhibit spatial autocorrelation, and (2) the random disturbances have equal variance. When OLS model is applied to spatial data, these two laws are violated because of the non-stationary spatial distribution of natural data (land cover, and landscape metrics) and socioeconomic data (GDP and population density). Thus, OLS model only reflects global information and lacks the ability to explain the local relations. Relationships at different positions will be hidden. In addition, because of the similar geographical environment and the human disturbance, the landscape features of adjacent areas are more consistent than distant areas, and the landscape metrics will also exhibit spatial autocorrelation. Therefore, when exploring the relationship between landscape patterns and urbanization, the performance and interpretation power of OLS model is restricted. For the above reasons, OLS is no longer considered applicable to the study of relationships between landscape evolution and its driving forces.

Geographically weighted regression (GWR) reflects the spatial characteristics of relationships by constructing local regression equations at each grid in the study area, thereby avoiding the problems of spatial autocorrelation, heterogeneity, and non-stationarity (Brunsdon et al., 1996; Su et al., 2012; Hu et al., 2015; Tenerelli et al., 2016). The GWR model can compute the regression coefficients for each location to describe a spatial relationship precisely, and the distribution of residuals of GWR is more random in space than that of OLS (Foody, 2003). GWR has been widely used in spatial correlation studies (Su et al., 2016, 2017). For example, Tu and Xia (2008) used GWR to explore the spatial relationship between land use and water quality under the background of urbanization. Gao and Li (2011) applied GWR to explore the spatial non-stationary relationship between urban surface temperature and environmental variables, and demonstrated that GWR was an effective method for solving the geo-spatial non-stationarity problem. Pribadi and Pauleit (2016) studied the relationship between peri-urban agriculture and urban socioeconomic system at village and sub-district scales, and showed that GWR could identify the different impacts of economic activity, poverty and food security in various regions.

In the first decade of the 21st century, Beijing City experienced rapid urbanization (Peng et al., 2016a), and landscape patterns changed significantly. Land use in Beijing City is diverse, including highly urbanized areas, suburbs experiencing rapid urbanization, and well-preserved forest lands in the northwest of the city. The differences in urban development levels and terrain factors will inevitably cause spatial differences in the driving forces, so GWR is well-suited to examining the relationships between landscape changes and urbanization. The purpose of this paper is to explore the spatial heterogeneity of urbanization impact on landscape patterns in Beijing City using GWR. In particular, the main research objectives are as follows: (1) to use landscape metrics to identify the characteristics of landscape patterns in Beijing City during 2000 and 2010; (2) to explore the spatial non-stationarity of urbanization impact on landscape patterns; and (3) to compare the impacts of different urbanization factors on landscape patterns.

2. Methodology

2.1. Study area and data source

Beijing City is located in the north of the North China Plain at longitudes from 115°25′E to 117°30′E, and latitudes from 39°28′N to 41°05′N, with a total area of approximately 16,400 km^2. The elevation of terrain in Beijing City is high in the northwest and low in the southeast. Mountain area accounts for about 62% of the total area at elevations between 1000 m and 1500 m, and plain area is flat and open, accounting for about 38% of the total area at elevations between 20 m and 60 m. Beijing City is in a typical northern temperature zone, with sub-humid continental monsoon climate. The annual average temperature in Beijing City is 12.3 °C, and annual precipitation is 572 mm. Beijing City has 16 districts including Dongcheng, Xicheng, Haidian, Chaoyang, Fengtai, Shijingshan, Mentougou, Fangshan, Tongzhou, Shunyi, Changping, Daxing, Huairou, Pinggu, Yanqing and Miyun. According to urban and rural differences and topographical features, Beijing City can be divided into five urban development zones (Fig. 1): (1) Downtown, i.e. the inner city, including Dongcheng and Xicheng District; (2) Suburb, including Haidian, Chaoyang, Fengtai and Shijingshan District; (3) Outer suburb (in the plain), including Tongzhou, Shunyi and Daxing District; (4) Outer suburb (in semi-mountainous areas), including Pinggu, Changping and Fangshan District; and (5) Outer suburb (in mountainous areas), including Huairou, Mentougou, Yanqing and Miyun District.

Beijing city has a mosaic of complex landscape types. Under the comprehensive influence of the natural environment and social economy, urban construction land, suburban cultivated land and outer suburban ecological land in Beijing City exhibit a circular structure with the downtown as the core, and this structure is also consistent with the terrain of Beijing City. Construction land accounts for 20.92% of the total area in Beijing City. The suburb plain areas are dominated by cultivated land, and most of the mountainous areas in the northwest outer suburb are forest land, accounting for 13.93% and 46.18% of the total area of Beijing City, respectively in 2010.

Beijing City is the center of China's political activity, culture, science