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Urban growth and its determinants across the Wuhan urban agglomeration, central China

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ABSTRACT

China has witnessed rapid urban growth over the past two decades, which has resulted in vast ecological and environmental issues, both in urban and peri-urban areas. It is therefore extremely important to explore the driving factors, and thus gain an insight into the process of urban growth, to be able to provide help for urban planning and policy making. This paper examines the features and spatial determinants of urban growth in the Wuhan urban agglomeration (WUA) from 1988 to 2011. Four landscape metrics (patch density, landscape shape index, aggregation index, and total area) were selected to characterize the urban landscape features at two scales (5 km and 10 km grid sizes). Spatial regression models were then used to explore the relationships between urban landscape change and its spatial determinants. The results showed that the urban area of the WUA increased from 4.19 × 104 ha in 1988 to 49.29 × 104 ha in 2011, with an annual growth rate of 46.75% over the past two decades. The WUA landscape has also become more fragmented and irregular. Spatial autocorrelations were common in the urban growth changes at the two different scales. Both physical and proximity factors have significantly influenced the urban landscape changes, and they have varied with time and scale. Among these variables, all the levels of road network have had a considerable effect on the shape and density changes of the urban landscape, while distance to railway and highway did not show obvious effects on the total area change of the urban growth. In addition, city center has had an increasing effect on patch density, and a decreasing impact on the total area of the urban landscape. The different land-use policies should be compromised and reconciled so that the objectives of promoting socioeconomic development and farmland protection can be balanced. These results could help us to better understand the process of urban growth, and thus have important implications for urban management and policy making in metropolitan areas in developing countries.

Introduction

Since the implementation of market-oriented economic liberalization reform in 1978, China has experienced an unprecedented degree of urbanization, which has been characterized by rapid economic and spatial urban growth, as well as a high rate of rural–urban migration (Chen, Liu, & Tao, 2013). According to the United Nations (2012), the projected urban population of China will reach more than one billion by 2050. Such a massive population growth will inevitably increase the demand for urban land areas. Although urbanization has boosted the economic development and improved the nation's quality of life, it has simultaneously brought about adverse impacts, such as agricultural land loss (Liu, Wang, & Long, 2008), an increase in the risk of soil and water pollution (Chen, 2007; Su et al., 2011), as well as local and regional climate change (Kalnay & Cai, 2003). In this context, it is crucial to characterize urban growth patterns and to understand the driving factors, as these factors are fundamental for designing a sustainable land-use policy.

The spatial form and extent of urban growth comes from its complex driving factors, which include physical factors, socioeconomic factors, neighborhood factors, and land-use policy (Li, Zhou, & Ouyang, 2013). In order to determine the impacts of these factors

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on urban growth, conventional statistical methods, such as multiple linear regression (Lu, Wu, Shen, & Wang, 2013; Müller, Steinmeier, & Küchler, 2010), bivariate regression (Ma & Xu, 2010; Wu & Zhang, 2012), and logistic regression (Cheng & Masser, 2003; Dendoncker, Rounsevell, & Bogaert, 2007; Luo & Wei, 2009; Reilly, O'Mara, & Seto, 2009; Shu, Zhang, Li, Qu, & Chen, 2014) are widely employed. However, these methods are unable to incorporate the spatial autocorrelation relationships existing in the spatial variables, as they hypothesize that these variables are spatially independent and identically distributed (Anselin & Griffith, 1988; Overmars, De Koning, & Veldkamp, 2003; Páez & Scott, 2005). Urban growth is a spatially conditioned process and the outcome at one location will be partially affected by other locations (Páez & Scott, 2005). Meanwhile, the variables that determine the urban land-use transition always exhibit spatial autocorrelation. Therefore, the spatial associations between the driving factors and between the dependent variables in urban growth analysis should be considered.

In addition, many studies on urban growth in China have focused on large individual cities such as Beijing (Li, Zhou, & Ouyang, 2013), Shanghai (Zhang, Ban, Liu, & Hu, 2011), Nanjing (Luo & Wei, 2009) and Guangzhou (Lu et al., 2013; Ma & Xu, 2010). However, there have been few studies of spatial growth and its drivers for urban agglomerations at a regional scale in developing countries. Urban agglomerations have become the fundamental regional unit in global competition and the international division of labor (Scott, 2001). According to the report of Fang, Song, Zhang, and LI (2005), in China, 28 city agglomerations cover only 22% of the entire territory; however, they include 44.4% of the total population, 60.4% of the non-agricultural population, 62.3% of the fixed asset investment, 76.9% of the economy, 77.7% of the industrial production, 70.0% of the retail sales of consumer goods and 95.8% of the third industry value. Meanwhile, they also provide 67.3% of the financial revenue, 73.1% of the total imports, 80.4% of the total exports, 94.2% of the foreign investment and 40.9% of the food. Therefore, more studies of the specific causes and characteristics of the urban growth of urban agglomerations in developing countries, especially in China with its particular institutional characteristics, are urgently needed.

This study uses remote sensing (RS) and a geographic information system (GIS) to present a long time series dynamic monitoring of the process of urban growth of the Wuhan urban agglomeration (WUA) over a period of nearly 23 years. Based on the monitoring results, we apply landscape metrics to characterize the urban growth patterns at different scales, and we identify the spatial determinants by employing a spatial regression. Finally, an analysis of the effects of land-use policy on urban growth is given in the Discussion Section.

Method

Study area

The WUA, located in the east of Hubei province in central China, is one of the most densely populated and fastest growing areas in the Yangtze Economic Zone and the rest of central China. The region is also called the Wuhan "1 + 8" city circle and includes Wuhan, which is the capital of Hubei province, eight prefecture-level cities, and 22 county-level cities (Fig. 1). It covers an area of approximately 58032 km^2, and had a population of approximately 30 million in 2010. The city of Wuhan, which is usually regarded as the "thoroughfare to nine provinces" and the center of the WUA, is the largest inland rail and road transportation hub of China. Wuhan is located within 1200 km of China's six major metropolises: Beijing, Tianjin, Shanghai, Guangzhou, Xi'an, and Chongqing. The two transportation arteries of China – the Yangtze River that runs from west to east and the Jingguang Railway that runs from north (Beijing) to south (Guangzhou) – intersect in Wuhan. In addition, five major country-network railways also meet at Wuhan, and result in the WUA being the connection leading to northern, southwestern, southern, and eastern parts of China. These advantages have resulted in this region becoming the economic, industrial, transportation, and information center of central China.

Since the strategy of "promoting the central region" was launched in 2004, the WUA has shown rapid economic growth, with GDP increasing from 270.76 billion RMB Yuan in 2001 to 964.08 billion in 2010. The urban population has also increased from 10.76 million in 2001 to 13.56 million in 2010. At the same time, this area has witnessed a significant urban land expansion. As the capital of Hubei province, as well as the center of the metropolitan area, Wuhan also plays an important role in the economic development of other cities. The GDP of Wuhan has increased more than three times from 135 billion in 2001 to 557 billion in 2010. All of these conditions mean that the WUA has been considered as a pilot area by central government to implement national resource saving and environmentally friendly society-integrated support reform, and to test various land-use policies such as land consolidation and the "increasing vs. decreasing balance" strategy.

Data processing

A multi-temporal Landsat TM/ETM + imagery time series dataset covering 5 years (1988, 1995, 2000, 2005, and 2011) was employed to map the land-use/cover of the WUA. Prior to classification, atmospheric correction was performed to standardize all the images to common spectral characteristics. Each image was then geometrically rectified to the same projection in two steps. At first, a topographic correction was used to correct the 2011 images, based on a topographic map. Next, an image-to-image registration based on the 2011 images was used to ensure that all the images had the same projection. The root-mean-square error (RMSE) was limited to within 0.5 pixels (15 m). A predetermined classification scheme of five land-use/cover types, namely urban land, farmland, forest, water, and bare land, was used to implement the classification. For our study, the supervised maximum likelihood classifier in ENVI 4.8 software was employed to classify the images. In order to ensure that all the land-cover types were adequately represented by the training samples, 180–200 training samples for each image were randomly selected for classification. A total of 1200 ground-truth samples, including both non-urban and urban pixels, were selected by a field survey in July 2012, to assess the accuracy of the classification. The overall accuracy and the Kappa coefficient of each land-cover map were above 85% and 0.72, respectively, which indicates that the classifications could satisfactorily represent the real landscape (Janssen & Van der Wel, 1994; Landis & Koch, 1977). The urban land-cover data were then converted to raster format by the use of ArcGIS software.

Quantifying urban growth patterns

Landscape metrics are important when quantifying urban growth. Based on the core set of 10 metrics proposed by Botequilha Leitão and Ahern (2002), we selected four class-level metrics to reflect the characteristics of the urban growth patterns (Table 1): patch density (PD), landscape shape index (LSI), aggregation index (AI), and total area (TA). These metrics have a low redundancy and are capable of quantitatively describing urban growth patterns (Botequilha Leitão & Ahern, 2002). In our study, 5 km × 5 km and 10 km × 10 km sampling blocks generated by the FISHNET module in ArcGIS 9.3 were used as the basic units for calculating all the