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Spatio-temporal analysis on built-up land expansion and population growth in the Yangtze River Delta Region, China: From a coordination perspective

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ABSTRACT

Revealing the temporal and spatial changes on built-up land expansion and population growth is extremely important for city's sustainable development. Although the differences in land and population growth have been examined, the range and the influential factors of such a gap have not been fully studied. In this research the ratio of the land expansion rate to the population growth rate is used as coordination degree to identify the trend of the "land-population" coordination with the case study of the Yangtze River Delta Region, China by means of spatial analysis and regression. Results indicate notable built-up land expansion and demographic change in the research area. The coordination degree increased from a value of 2.28 in Period I (1990–2000) to 3.12 in Period II (2001–2014), further away from the ideal value (i.e. 0.8–1.4). Overall, the coordination level in central region of the study area is better than those of the North and the South. Regression analysis shows that neighborhood and per capita GDP are two significant influential factors of built-up land expansion and population growth in both periods, and that the impact of "neighborhood" has intensified over time. These findings demonstrate that socioeconomic situation of geographically neighboring cities contribute a lot to the coordinated development of the local population and land.

1. Introduction

The expansion of built-up land and the growth of population are two outstanding factors of urban growth. Discussions on them have been raised for a long time. The essence of the urban growth, to some extent, is a process of population agglomeration, accompanied by increasing the size of cities (Yuan, 2014). Over the past few decades, massive migration to cities has placed heavy pressure on land resources, especially in developing countries where the desire for prosperous economy still prevails (Liu et al., 2014; Wu & Zhang, 2012). Population growth requires expanding and intensifying arable land, while it also accelerates the transformation from agricultural land to residential and industrial land (Kaplan et al., 2011; Place & Otsuka, 2001; Seto et al., 2012; Shoshany & Goldshleger, 2002; Verburg & Bouma, 1999). Under this circumstance, land-use change occurs continually in many coastal regions of China, such as Yangtze River Delta Region, Pearl River Delta Region and Bohai Rim (Guo, Wang, Qiu, Wang, & Liu, 2009; Long, Tang, Li, & Heilig, 2007; Weng, 2002; Zhu, He, & Zhang, 2001). Among all these regions, built-up land expansion is considered as the immediate result of land use change. Therefore, the question remains what is the coordination trend of "land-population" growth over a period of time and how they can be managed to contribute to the sustainable development.

The term "coordination" in most relevant research is described as the balance between land expansion and population urbanization. Many studies have analyzed the coordination between land expansion and population growth during the process of city development in general. Accumulating evidence suggests that the land area always expands faster than population size during the process of city development, meaning that the population density decreases in the city and land use intensity declines (Luo & Wu, 2015; Marshall, 2007; Seto, Fragkias, Güneralp, & Reilly, 2011; Weber, Sloan, & Wolf, 2006). Additional studies that focus on urban ecology have pointed out that landscapes have been tremendously dynamic during the breakneck urban growth (Su et al., 2016; Wu, Xiang, & Zhao, 2014). Environment pollution, segregation and social vulnerability reduction emerge and continue to fester due to the uneven distribution of land and population in space and time (Alghais & Pullar, 2018; Cutter & Finch, 2008; Rudd, Malone, & Bartlett, 2017; Subasinghe, Estoque, & Murayama, 2016). Meanwhile, geographical and spatial analyses with new data sources are

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adopted extensively in further exploring the coordination (Codjoe, 2007; Hegazy & Kaloop, 2015; Shen, Wu, & Fang, 2014; Zhang et al., 2013). Related researches established a multi-criteria index on land-use conflicts for increasing population pressure (Iojă, Niţă, Vânău, Onose, & Gavrilidis, 2014). They also analyzed the spatial patterns of land use change (Hegazy & Kaloop, 2015; Basse, Omrani, Charif, Gerber, & Bódis, 2014), and explored the spatial distribution of population and settlement (Jia, Qiu, & Gaughan, 2014; Linard, Gilbert, Snow, Noor, & Tatem, 2012) and proved the correlation between population density and land-use change (Bagan & Yamagata, 2015; Gong, Yuan, Fan, & Stott, 2015). Some researchers also tried to build a coordinated coupling model for analyzing the internal relationship between land expansion and population growth. Influential factors like industry, economy and environmental indicators are considered into the model to analyze urbanization harmony degree (Cao, Zhang, Pan, & Zhang, 2012; Giannecchini, Twine, & Vogel, 2007).

The inadequacy of these studies was that they either focused on macroscopic scale like an entire country (Chen, Zhang, Wu, & Chen, 2010; Zhu, Zhang, Can, Jiao, & Wang, 2014), or on microscopic scale such as a single province (Wang & Xia, 2015). Few attention was paid on the research of influential factors of the "land-population" coordination in a scale of a specific across-provincial region – mesoscopic scale. Analyses on all of the scales are significant for understanding the rules of land and population changes. Existing studies have shown that there is a gap between land expansion and population growth, but it is still unclear on the range and the cause of such a gap. The analysis on an across-provincial region, especially on a developed economic zone can help answer the question and promote the sustainable development of the region.

This research, therefore, aims at assessing temporal and spatial variation on the coordination between built-up land expansion and population growth in the Yangtze River Delta, China. A coordination model is proposed to describe the differences of land and population growth. Remote sensing image of built-up land and raster image of population (1990, 2000, 2014) are collected and processed to evaluate the temporal and spatial variation with the method of mean center and hot spot analysis. Then, a regression model is used with socio-economic factors. A new explanatory variable "neighborhood" is introduced to explore the influential factors of the cities' coordination during the periods of economic prosperity from 1990 to 2014 in the Yangtze River Delta.

The rest of this paper is organized as follows. Section 2 introduces the research method and data for the study. Section 3 describes the results of the spatial analysis and regression in the Yangtze River Delta Region on the coordination between built-up land expansion and population growth. Section 4 discusses the research results and section 5 provides conclusions of this study.

2. Research method and data

2.1. Study area

The Yangtze River Delta Region is located in the alluvial plain of the Yangtze River Delta, including Shanghai Municipality, Zhejiang Province and Jiangsu Province. It is the China's largest economic zone with about 186800 km^2 land area, 156 million population, and almost 20% of the GDP in the country. The climate is mainly subtropical monsoon with four distinct seasons. The Yangtze River Delta Region is still in the period of rapid development and has a substantial attraction to immigrants (or floating population). This research covers the entire Yangtze River Delta Region, including one direct-controlled municipality, three sub-provincial cities, and 22 prefecture-level cities (See Fig. 1).

2.2. Coordination degree

For purposes of this study, coordination is defined as a comparison of the development situations between land expansion and population growth to describe the balance between these two objects. Therefore, in terms of land expansion and population growth, we choose the ratio of the land expansion rate to the population growth rate as the coordination degree. To explore the coordination between these two objects, we first calculate the coordination degree, with the following formula:

$$C_t = \frac{\Delta L_t / L_{t-1}}{\Delta P_t / P_{t-1}} \times 100\% \quad (1)$$

$$\Delta L_t = L_t - L_{t-1} \quad (2)$$

$$\Delta P_t = P_t - P_{t-1} \quad (3)$$

in which, C in year t is a function over time with parameters L_t (built-up land area in year t), L_{t-1} (built-up land area in year t-1), P_t (population in year t), *and* P_{t-1} (population in year t-1). The population here means the number of residents. As the Yangtze River Delta is located in the coastal area, urbanization there develops rapid, and large quantities of people migrate from inland. The growth of the population is mainly due to the mechanical growth of the migrant population. For the ideal coordination degree, it has been widely recognized that urban development can be considered efficient if the coordination degree is around 1.12 (Lin & Mao, 2008; Wang & Xia, 2015; Yang, Feng, Zhao, & Zhen, 2013). Otherwise, the city may confront some issues concerning sustainability, like land use inefficiency or restriction. However, urban growth can be more elastic due to social development and technical progress. A fair range of "0.8–1.4" should be more feasible than a single value of "1.12" as the criteria to evaluate the rationality of urban growth.

2.3. Spatial analysis

To distinguish the geographical distribution of built-up land expansion and population growth, the natural breaks (Jenks) method is chosen to divide the built-up expansion rate and population growth rate into five classes respectively. Besides, mean center and hot spot analysis are two main spatial analysis tools in this study. A mean center is often used to find a specific location where the transportation costs can be minimized. In practice, it can help determine the land expansion and population growth focuses in a given year. Besides, we can grasp the variation trend of the focus location by comparing different periods. As for hot spot analysis, it is a useful tool identifying the hot and cold spots with statistically significant characteristics. Scholars use this method to analyze the probability distribution, such as outbreak of disease and crime. To some extent, highlighting the hot and cold spots of population growth with Geographic Information System (GIS) can help find the cluster phenomenon of coordination degree distribution.

2.4. Data

The built-up land data for this paper were collected from the "Global Human Settlement Layer" (Landsat image collections GLS1990, GLS2000 and ad-hoc Landsat 8 collection 2014) with a spatial resolution of 250 m by 250 m (Pesaresi et al., 2015). Each grid cell (250 m × 250 m) contains a numerical value to show the construction state of the position. The values are typically expressed with a continuous value ranging from 0 to 1 to present the proportion for building footprint area within the total size of the cell. The population data for 1990, 2000 and 2014[1] were provided by CIESIN Gridded Population of

[1] Because of unavailability of population grids in 2014, we use population data in 2015 for 2014.