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Simulating the spatial dynamics of urban growth with an integrated modeling approach: A case study of Foshan, China

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ABSTRACT

Foshan is one of China's rapidly industrializing cities, and the municipality has undergone significant urbanization in the past 20 years. To investigate the urban development of Foshan municipality, we used an integrated modeling approach based on Markov chain (MC), logistic regression, and cellular automata (CA) to study dynamic changes in land use. An MC and neighborhood transfer matrix were used to determine the influence of the central cell and neighborhoods, while logistic regression was fitted by factors derived from a principle component analysis to produce probability maps of the driving forces. The accuracy of the Markov-logistic-CA model was sufficient for predicting processes of change in urban land use compared to other models. Then three scenarios were constructed through the setting of potential land use policies, land demands, and mapping future public transportation to reflect the possible urban patterns of Foshan in 2025. The simulation results indicated that a spread-out urban pattern will be dominant in Foshan in the future, while zoning development, with the preservation of ecological features in rural-urban areas, will relieve the environmental deterioration of the Foshan municipality.

1. Introduction

Urban land use change (LUC) has received much attention in the field of urban sustainability in recent years (Workshop et al., 2015). The growing problem of urban sprawl in most metropolitan areas is associated with large releases of hazardous air pollutants and heat island effects. However, poor land use decisions could have more radical impacts on the urban environment and ecology. For example, due to loose planning regulations, excessive rural industrialization since 1995 in the Yangtze River Delta has led to isolated manufacturing industries being scattered throughout the entire region, resulting in a significant loss of agricultural land and degradation of regional environmental quality (Tian, 2015). The lack of prior knowledge on these ecological consequences of LUC made it difficult to balance urban development and urban sustainability. Therefore, modeling has become a useful tool for understanding urban systems and accessing the potential impacts of LUC on ecological systems (Puertas et al., 2014).

Understanding trends in urban growth is crucial to realize sustainable development. In recent years, different studies have quantitatively modeled the spatiotemporal changes in different land uses and have provided guidance for urban sustainable management (Verburg et al., 2002; Huang et al., 2009; Al-Ahmadi et al., 2009a,b; Mitsova et al., 2011; Rienow and Goetzke, 2014). He et al. (2006) coupled a system dynamic (SD) model with a cellular automata (CA) urban growth model, and simulated future urban expansion in Beijing under a limited water supply. Chandralal et al. (2009) extended a constrained CA model to effectively simulate the dynamics of shifting cultivation. Among these studies, the empirical estimation method and dynamic simulation are two major approaches used during the past two decades for predictive land use modeling. Empirical estimation models use statistical methods to create a probability map to capture the complexity of LUC in the real world and identify the contributions of explanatory variables based on historical data (Geoghegan et al., 2001; Tian et al., 2011). In previous studies, a receiver operating characteristic (ROC) curve and its statistics were used in the model selection and validation process. However, the empirical estimation method often uses historical data to classify LUC, and it is crucial to eliminate the spatial effects of the spatial variable and consider the correlations between variables in the fitting process.

Recently, a combination of empirical estimation and dynamic simulation has been widely adopted in urban modeling studies (Alberti and Waddell, 2000). CA is a typical representative dynamic simulation model. In terms of LUC, CA models simulate dynamic processes based on the assumption that the land use of the central cell changes through the interaction of land uses in the neighborhood, and can identify how cities have developed by incorporating

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various social and economic factors into transition rules (Schaldach et al., 2011; Mitsova et al., 2011; Yang et al., 2014; Tan et al., 2015). Several statistical methods, including regression (Liu et al., 2008), Markov chain (MC) (Arsanjani et al., 2012), and classification algorithms based on machine learning theory (Rienow and Goetzke, 2014), have been coupled with CA models to simulate the dynamic process of urban growth. Yang et al. (2012) and Guan et al. (2011) applied a first-order MC to a CA model to predict complex LUC under continuous urbanization. For larger areas, with multiple administrative districts and complex urban land use patterns, further study is needed to improve model performance.

Unlike urbanization in the West, the most distinct feature of the urbanization process in China since the late 20th century is the predominately urban growth in densely populated peri-urban areas, with multiple driving forces (Sui and Zeng, 2001). Therefore, detailed socioeconomic information is required to capture the dynamic process of migration from rural to urban areas.

As a tool for system analysis, the established models should provide information on the potential impacts of urban development strategies (He et al., 2005; Al-Ahmadi et al., 2009b; Vaz et al., 2012). Fuglsang et al. (2013) established three storylines under specific transportation paradigms and economic trends to access the unknown future conditions for the entire Copenhagen metropolitan area. In our study, by incorporating future public transport networks, urban planning policies, and land demands, three scenarios were built to predict future possible urban patterns in the municipality of Foshan, one of China's fastest-emerging industrializing cities.

Therefore, we developed the Markov-logistic-CA model, which integrates an MC, logistic regression, and CA rules through a multicriterion evaluation (MCE) method. Various evaluation indicators were used to assess the performance of the modeling approach applied to Foshan. By combining established scenarios for the period of 2015–2025, the complicated landscape patterns of Foshan were predicted and the consequences of urban development strategies were examined.

2. Study area and data

2.1. Study area and data sources

The municipality of Foshan is located in the Pearl River Delta region of China (110°00′–115°00′ E, 22°00′–25°00′ N) to the west of Guangzhou City and north of Zhongshan City, and consists of one of the most dynamic urban agglomerations in China. It covers a total area of 3796.99 km^2, and the population reached 7 million in 2010. The five districts of Chancheng, Nanhai, Shunde, Gaoming, and Sanshui have been subordinate to Foshan since 2003 (Fig. 1). Chancheng is the center of Foshan, while Nanhai and Shunde are adjacent to Guangzhou in the east. The elevation of Foshan decreases from northwest to southeast, resulting in large variation in ecological features. About 84.2% of the municipality's forest area is located inside Sanshui and Gaoming. Agricultural and wetland areas are common in the delta plain formed by the entrance of a river into the peri-urban area. The urban area has expanded significantly in the eastern plain.

As one of the most important manufacturing bases for not only China, but also the world, Foshan is characterized by its rural industrialization and peri-urban sprawl (Tian, 2015). Chancheng, Nanhai, and Shunde are all top-ranked counties in China in terms of economic strength. The town of Shishan has developed from several small villages into the largest industrial town within Nanhai. Gaoming and Sanshui have also grown rapidly through economic development. As a result, the spatial pattern and landscape of Foshan has experienced huge and complex changes over the last two decades. The expansion of cities has created multiple environmental and

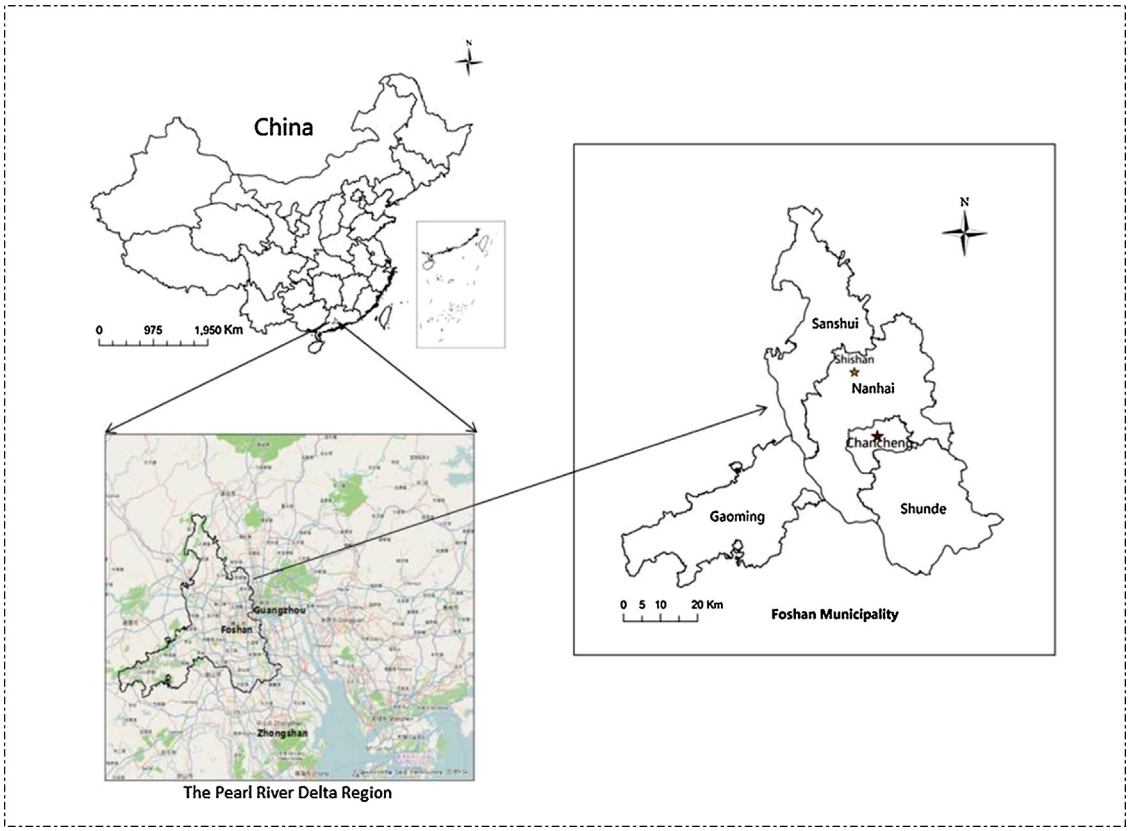

Fig. 1. An overview of the municipality of Foshan.