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Simulation of urban agglomeration ecosystem spatial distributions under different scenarios: A case study of the Changsha–Zhuzhou–Xiangtan urban agglomeration

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ABSTRACT

Changsha–Zhuzhou–Xiangtan is an urban agglomeration along the middle reaches of the Yangtze River, the development plan of which is listed as one of national strategic development. The eco-environmental quality of the Changsha–Zhuzhou–Xiangtan urban agglomeration concerns the ecological security of China. It is essential to discuss the method of creating urban agglomeration plans to increase ecological security. In this paper, the ecosystem distributions were mapped using the CLUE-S model incorporated with Gray Model (GM) (1, 1) and an auto-logistic regression model under the conditions of a natural increase scenario (NIS), a cultivated protection scenario (CPS) and an ecological protection scenario (EPS). We analyzed the change and conversion characteristics of ecosystems both in the study area and the junction of Changsha, Zhuzhou and Xiangtan. The results showed that the ecosystem change model developed in this paper performed well in mapping future urban ecosystem distributions. The change of the ecosystem spatial distributions showed us that the built-up ecosystem would expand in the future by transforming cultivated and green land ecosystems and that the boundaries between cities would be blurred. In the whole study area, the amount of converted area from cultivated and green land to built-up land was lower in CPS and EPS than in NIS. However, in the key area, the converted result was contrary to the whole study area. Although the CPS and EPS were beneficial to the eco-environmental protection of the whole study region, the sub-regional eco-environment should be given more attention to assure that the ecological security of the whole region remains safe.

1. Introduction

Urban agglomerations, which result from economic development and urbanization, are regions composed of a number of cities around regional economic core cities (He et al., 2013). The typical urban agglomerations in China include Beijing–Tianjin–Hebei, Pearl River Delta, Yangtze River Delta, and so on. Urban agglomeration expansions have changed the original ecological landscapes and ecosystem structures and threaten regional ecotopes (Zhou et al., 2015). As a result, regional ecological security is worsening. Therefore, it is essential to take measures to protect the environment and promote the harmonious development of human beings and nature. How can cities balance the contradiction between rapid development and ecological environmental protection to build an ecological urban agglomeration? Scenario analysis is an effective method to map the spatial distribution of urban agglomeration. Urban planners and policy makers can select a more reasonable mode of development and optimize the allocation of resources based on maps of urban agglomeration under different scenarios. Thus, scenario analysis is a significant method to maintain urban agglomeration ecosystem health.

An ecosystem change model is the key to scenario analysis, such as the Cellular Automata model (CA), system dynamics model (SD) and the Conversion of Land Use and its Effects model (CLUE). Pijanowski et al. (2002) incorporated the BP model into the CA model to study urban expansion and urban structure change. Saysel et al. (2002) built an SD model to simulate the ecosystems spatial change and analyzed the variation trend. Veldkamp and Fresco,

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1996 proposed the CLUE model. Verburg et al. (2002) developed the CLUE model and proposed the Conversion of Land Use and its Effects at Small regional extent model (CLUE-S) to simulate ecological system changes at a small regional extent. The CLUE-S model has been developed and applied to many fields (Verburg et al., 2008; Overmars et al., 2007; Trisurat et al., 2010; Castella et al., 2007). For example, Fox et al. (2012) used the CLUE-S model to simulate the land-cover change in the montane mainland southeast of Asia. However, there are some limitations of these models. The CA model cannot simulate the competition between ecosystems and has difficulty incorporating expert knowledge (Mas et al., 2014). The ordinary regression models map the future ecosystem distribution according to past distributions, without considering the uncertainty. The CLUE-S model takes social–economic and natural factors into account and performs better than the other ecosystem change models (Jiang et al., 2015).

A spatial correlation effect commonly exists in geographic space. The selected driving factors are likely to be incorrect when the spatial correlation is ignored (Overmars et al., 2003). Auto-logistic regression models (AL), which incorporate auto-covariates based on logistic regression models, are available to eliminate the spatial correlation effect. AL models have been commonly used in modeling ecological diversity (Augustin et al., 1996; Syartinilia and Tsuyuki, 2008). Studies show that incorporating an auto-logistic regression model is an effective method to improve the performance of the CLUE-S model (Lin et al., 2011; Wu et al., 2010). The CLUE-S model is widely used in landscape change studies of China's urban agglomerations. Dai and Zhang (2013) simulated landscapes under five different scenarios in Zhangye city, China, using the CLUE-S model. Hu et al. (2013) incorporated a Markov model into the CLUE-S model and simulated the landscape of Beijing for 2015 under two scenarios. Zheng et al. (2015) used the CLUE-S model incorporated with a Markov model to simulate land use changes of urban renewal districts under four scenarios for 2018.

The Changsha–Zhuzhou–Xiangtan region is one of the most important urban agglomerations. The ecological isolation zone between Changsha, Zhuzhou and Xiangtan has been destroyed and the cultivated areas and woodlands and wetlands are shrinking due to the expansion of the built-up ecosystem. The regional ecological security problem has become more prominent. Currently, construction of eco-cities is advocated in China. How to design the landscape to improve the ecological security of ecosystems in urban agglomeration is an important question to explore. This paper takes the Changsha–Zhuzhou–Xiangtan urban agglomeration, one of the most important agglomerations of the Yangtze River, as the study area. An auto-logistic regression model is incorporated into the CLUE-S model to map the ecosystem distribution of Changsha–Zhuzhou–Xiangtan urban agglomeration for 2014, 2019 and 2024 based on observed maps from 1995, 2000, 2005 and 2009 under the conditions of a natural increase scenario (NIS), a cultivated protection scenario (CPS) and an ecological protection scenario (EPS). The characteristics of the ecosystem patterns are analyzed to provide suggestions for urban planning and eco-city construction.

2. Materials and methods

2.1. Study area

The Changsha–Zhuzhou–Xiangtan region is an urban agglomeration located along the middle reaches of the Yangtze River. The core region of Changsha–Zhuzhou–Xiangtan is located in the middle-east of Hunan province, which is located in central China. The Changsha–Zhuzhou–Xiangtan urban agglomeration (CZT) (Fig. 1) is composed of the main part and the perimeter zone of Changsha, Zhuzhou and Xiangtan (Yang et al., 2012), between 112°36′–113°17′ E and 27°37′–28°33′ N, with an area of 4588 km^2. The Xiangjiang River is the biggest river of the CZT, crossing the study area from south to north. The main urban area of Changsha and Zhuzhou is located along the right bank of the Xiangjiang River, and Xiangtan is located along the left bank. The distances from Changsha to Xiangtan and from Zhuzhou to Xiangtan are 40 km and 20 km, respectively. With the urban development, the distances between the cities are decreasing and the centrality of the cities is gradually expanding. The CZT is the regional economic core of Hunan province. The built-up area has expanded since the 1990s. From 2000 to 2008, the built-up area increased by 171 km^2 at the cost of the cultivated land and woodlands. According to the "Changsha–Zhuzhou–Xiangtan urban agglomeration regional development plan" proposed in 2008, the ecotype of urban agglomeration is going to be constructed to improve regional ecological security.

Table 1
The definition of BE, GE, CE and WE (Ouyang et al., 2015).

Ecosystem	Definition	Examples
BE	Human settlement, mainly of artificial surface	Residential area, urban green land
GE	Land surface is mainly of tree, bush and grass	Woodland, grass land
CE	Land surface is mainly of crops	Cultivated land, garden plot
WE	Land surface with water	Rivers, lakes, marsh

2.2. Materials

Two types of data were used in this paper, including ecosystem distribution maps and the collection of explanatory data.

A series of Landsat TM/ETM data for CZT accepted in 1995, 2000, 2005 and 2009 were explored in this study at a resolution of 30 m. The CZT ecosystem has been classified into five classes (defined as Table 1), including the built-up ecosystem (BE), green land ecosystem (GE), cultivated ecosystem (CE), wetland ecosystem (WE) and others by the Support Vector Machine (SVM) method. The GE was composed of woodland ecosystems and urban green land ecosystems. The observed maps (Fig. 2) of the CZT ecosystem were used to simulate and validate ecosystem demand areas, simulate ecosystem distributions and analyze the characteristics of change under different scenarios for the years of 2014, 2019 and 2024.

The natural resource data were used to select natural driving factors, including slope, aspect (−7∼639 m), and soil type (e.g., primary soil, semi-hydromorphic soil, anthropic soil, ferrasol, impervious surface, lake reservoir, rivers and island). Social–economic data (e.g., settlement, town center, river net and transportation data) were used to select social–economic driving factors based on distances from stations, city centers, town centers, county centers, village centers, express ways, railways and the Xiangjiang River and its branches. The limited developing regions and ecosystem areas were set in the CZT developing plan, and the cultivated protection scenario and ecological protection scenario were set according to the plan.

2.3. Methods

This paper simulated ecosystem demand areas for 2000, 2005 and 2009 using the GM (1, 1) model based on observed maps for 1995, and the simulated demand areas were validated by observed maps for 2000, 2005 and 2009. If the simulated demand areas met the required accuracy, the ecosystem demand for 2014,