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Interoperable scenario simulation of land-use policy for Beijing–Tianjin–Hebei region, China

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ABSTRACT

In land-use change studies, scenario simulations cannot be effectively realized because of Geographic Information System (GIS) temporal-spatial interoperability bottlenecks. Based on a previous temporal-spatial dynamics method (TSDM) established by the author, this study extended the previous model and proposed an extended TSDM (ETSDM): (1) The neighborhood of cellular automata (CA) model was extended to a "Square + Circle" neighborhood, making the neighborhood more realistic and improving the simulation accuracy to a certain extent. (2) To achieve dynamic data exchange between the CA model and GIS, the scenario simulation of temporal and spatial visual interoperability from a national planning scheme or spatial location delineation to planning implementation effects can be implemented. Based on land-use data for 1995, 2005, and 2013, the simulation accuracy of the ETSDM was verified and development patterns were predicted under the following scenarios. Scenario 1 used the independent Beijing, Tianjin, and Hebei Province, and was designed as a blank control. Scenario 2 used the coordinated Beijing–Tianjin–Hebei (BTH) development area. This area was projected in order to study the probable land-use patterns in temporal and spatial dimensions under the effects of national policy data. Scenario 3 added the Xiongan New Area on the basis of Scenario 2, which was used to explore the influences of sudden land-use policies on regional land-use patterns. The results indicate that: (1) A "Square + Circle" neighborhood details the type of neighborhood cells and has an approximately 1% accuracy improvement relative to the general neighborhood rules; (2) According to the interactive operation in the model, land-use graph-number changes in the specific target region under different land-use policies can be monitored; and (3) Under different development policies, the built-up land gross of Beijing will be conserved approximately 600 km^2, along with the coordinated development of the BTH region and the establishment of the Xiongan New Area in 2030. At the same time, cropland conditions will be improved. A reason for the results may be that some of the non-capital functions will be transferred to Tianjin and Hebei Province under the national policies.

1. Introduction

Land use and cover change are largely influenced by human factors (Vitousek et al., 1997), especially the land-use policies from the government. Questions regarding how to efficiently manage limited land and realize sustainable development, especially in developing countries, have been the concern of government planners and also the focus of researchers. Simultaneously, government decision-makers must test the effectiveness of policy through the urban evolution simulation. Land-use models can effectively provide information about past land-use changes and forecast the future effects of land-use planning and policy, providing a reference for land managers to check the impact of the policy (Schmitz et al., 2014; Verburg et al., 1999). Many models are used to simulate and study future land-use scenarios. He et al. (2006) simulated land-use patterns in Beijing, China under various scenarios in 2020, according to a balance between supply and demand based on the integration of a system dynamics (SD) model and cellular automata (CA) model, Sakieh et al. (2015) conducted development comparison study of multiple scenarios for Karaj City, Iran in 2040 using a CA model and SLUETH model.

In recent years, an increasing number of researchers have used SD models (Han et al., 2009; Lauf et al., 2012) and CA models (Liang and Liu, 2014; Liu et al., 2015; Munshi et al., 2014; Wang et al., 2013) to study land-use changes and urban expansion, and so on. SD models are "top-down" and macro-quantity models. According to a variety of macro-driving factors and existing statistical data, SD models can be

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used to establish dynamic simulation models. However, SD models cannot handle spatial data or consider micro-dimension behavior (Guo et al., 2001). A CA model is a "bottom-up" micro-model that is widely used to simulate complex dynamic systems (Arsanjani et al., 2013; Onsted and Chowdhury, 2014). Nonetheless, CA cannot simulate macro-driving factors, such as government regulations. Therefore, we established a temporal-spatial dynamics method (TSDM), which integrated the SD and CA models (Liu et al., 2017). The TSDM realizes a complementary and deep integration between the SD model and CA model, and can simulate land-use changes in both the macro-dimension and micro-dimension, effectively improving the accuracy of simulation and prediction. At the same time, TSDM allows data to bidirectionally communicate between the SD and CA models, thereby increasing simulation authenticity. TSDM can easily obtain various simulation scenarios for land-use situations by setting different simulation parameters in the SD model.

Although TSDM has the above advantages, Geographic Information System (GIS) only plays a role in spatial visualization, and cannot effectively solve the following three problems: (1) How can national macroscopic land-use policy and long-term planning data be used? (2) How can a certain delineated area in the map be simulated and analyzed? and (3) How can the impact on future development evolve because of sudden national policy? Furthermore, traditional neighborhoods, such as the Moore and Von Neumann neighborhoods, do not consider the weight of different neighborhood cells on the center cell.

Beijing–Tianjin–Hebei (BTH) region is the largest economic area in northern China (Peng et al., 2016). Huge population pressure leads to over-urbanization and some ecological lands are not used properly (Xie et al., 2012). In the northern of the region, there are both agricultural lands and pastures. In order to prevent land desertification, the policy of returning farmland to woodland and grassland was implemented, which led to the land-use patterns change in the BTH region. The government has been committed to find a win-win mode to develop the economic and protect the environment at the same time. In 2014, the coordinated development of the BTH region was proposed to achieve the overall development of Beijing, Tianjin, and Hebei Province. In 2017, the Xiongan New Area was presented to further promote the development of the above three regions. The Xiongan New Area aims to load the non-capital functions and ease the pressure for Beijing.

Based on this, an extended TSDM (ETSDM) is proposed in this paper base on the previous TSDM. According to interactions with the GIS platform, temporal and spatial interoperability with GIS is implemented, effectively solving interaction between the temporal dimension and spatial dimension for macro-policy. Meanwhile, the authenticity of the simulation is increased by extending the neighborhood rules and refining the types of neighborhood cells. The ETSDM was created using the LOGO language through the NetLogo platform. The ETSDM was verified using land-use data for Beijing, Tianjin, Hebei Province, and the BTH region from 1995 to 2013. Based on the validated ETSDM, three land-use simulation scenarios from 2013 to 2030 for the BTH region were predicted and studied, with the aim of exploring the impact of national macro-policy on future land-use patterns in the BTH region and finding the key factors promoting land-use changes. Through the simulations, it is easy to examine the effect of the policies and gain the processes of land-use changes in the BTH region. The simulations aim to provide references for the government to better solve the "big city disease" problem for Beijing. Section 2 introduces the study area used in the paper as well as the data processing method. Section 3 mainly describes the extension and realization of the ETSDM in the method and scenario design. Section 4 describes the scenario simulation research for the study area. Section 5 presents an in-depth discussion about the extended neighborhood and predicted results. Section 6 presents conclusions.

2. Materials

2.1. Study area

The BTH region mainly includes Beijing, Tianjin, and Hebei Province, which is the circle of economy around the capital of China, located in the center of the Bohai economic zone (Tan et al., 2005; Wang et al., 2014). Beijing is the political, economic, and cultural center of China (Xie et al., 2017); Tianjin is the national first batch of coastal open cities from 1984, and is one of the four major municipalities in China; and Hebei Province contains 11 prefecture-level cities, such as Shijiazhuang, Baoding, Tangshan, and so on (Peng et al., 2016), and has a very large population in northern China. The BTH region land area is approximately 218,000 km^2. The region has more than 110 million residents and the Gross Domestic Product (GDP) reached 6.94 trillion yuan in 2015 (NBSC, 2016). Huge population pressure makes the regional environmental and resource problems particularly prominent. On the other hand, the increased population drives economic development. Therefore, government decision-makers are committed to searching for a win-win solution that can promote economic development while simultaneously protecting the environment and resources to achieve sustainable urban development. In 2014, Chairman Xi proposed a BTH region cooperation and development strategy to build a world-class urban agglomeration. In April 2017, the Communist Party of China Central Committee and the State Council decided to establish the Xiongan New Area as a centralized carrying ground for Beijing non-capital functions, aiming to build a green, ecological, and civilized new area. The coordinated development of the BTH region is mainly used to ease the non-core functions of Beijing and solve "big city disease" problems. Finally, the coordinated development of the BTH region is used to optimize urban spatial structures and improve the urban ecological environment.

2.2. Data processing

Land-use data for Beijing, Tianjin, Hebei Province, and the BTH region in 1995, 2005, and 2013 were selected for the simulation study. These land-use maps were obtained through visual interpretation based on Landsat TM/ETM data by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (Liu et al., 2005). The overall evaluation accuracies are higher than 94.3% (Liu et al., 2014). To effectively improve the operation efficiency of the NetLogo platform and simplify the model, the land-use types are reclassified into four basic categories: cropland, woodland and grassland, built-up land, and water body (Song and Deng, 2017; Song et al., 2015). The cropland refers to the lands where crops are grown. Woodland and grassland contains lands covered by trees and herbaceous plants. And in the BTH region, because the area of unused land is much smaller than the others and most patches of the unused land are within the woodland, unused land is reclassified as the woodland and grassland. Built-up land refers to urban and rural settlements and the lands used for factories, transportation facilities, and other sites. Water body contains the natural water bodies and the lands used for water conservancy facilities. Based on the land-use in 1995 for the above four regions, the simulation accuracies were calculated for 2005 under different resolutions: 200, 500, and 1000 m. At the same time, the areal differences of the above four regions, the visual effects of the land-use maps, and the operation time were also taken into account to determine that the land-use data for Beijing and Tianjin should be resampled to 200 m, while the data for Hebei Province and the BTH region should be resampled to 1000 m.

Previous studies have shown that highways, railways, and other environmental variables have a certain degree of impact on land-use changes (White and Engelen, 1993; Wu and Webster, 1998). Therefore, according to the availability and usability of the data, the following 11 environmental parameters were chosen as evaluation indicators: