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 km², 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
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 part 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; 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 km². 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 re-classified 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:
distance to provincial roads, distance to highways, distance to railways, distance to banks, distance to drugstores, distance to hotels, distance to markets, distance to restaurants, distance to schools, distance to hospitals, and distance to parks. These 11 parameters were selected in order to assess the impact of environmental factors on land-use changes. The selected environmental factors were acquired from Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences based on the project supported by the Ministry of Land and Resources of China. Additionally, we used population and GDP data, which were obtained from the Beijing Statistical Yearbook, Tianjin Statistical Yearbook, and Hebei Statistical Yearbook. Table 1 lists the details of the required data. To unify the controllable factors and increase the reliability of the contrast research, the coordinate systems for all spatial data were defined as the Universal Transverse Mercator (UTM) coordinate system.

3. Methods

3.1. TSDM introduction

The TSDM achieves data bidirectional communication between the SD model and CA model at the grid level, taking full advantage of the temporal and macroscopical dimensions of the SD model and combining the capacity of the CA model for local-scale spatial distribution. The TSDM is based on the SD model and establishes land-use scenario predictions according to the influence of macro-scale factors (such as land policy, population policy, etc.). The details for the SD model are described in Appendix A. The macro-factors, which are obtained from the SD simulation results, influence and control the land-use distributions in the CA model to acquire land-use patterns on the local scale. Simultaneously, TSDM calculates spatial indexes and passes the values to the SD model. Based on the above process, the bidirectional data

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Data used in the study.</th>
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<tbody>
<tr>
<td>Natural factors</td>
<td></td>
</tr>
<tr>
<td>Provincial road network</td>
<td>Shape</td>
</tr>
<tr>
<td>Highway network</td>
<td>Shape</td>
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<tr>
<td>Railway network</td>
<td>Shape</td>
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<td>Bank features</td>
<td>Shape</td>
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<td>Drugstore features</td>
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<td>Market features</td>
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<td>Restaurant features</td>
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<td>School features</td>
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<td>Hospital features</td>
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<tr>
<td>Park features</td>
<td>Shape</td>
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<tr>
<td>Social factors</td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>Continuous variable</td>
</tr>
<tr>
<td>Gross Domestic Product</td>
<td>Continuous variable</td>
</tr>
</tbody>
</table>

Fig. 1. ETSDM structure. Modified from Liu et al. (2017).
interaction between the SD model and CA model can be accomplished. These details are described in Liu et al. (2017).

3.2. Temporal-spatial interoperability between the CA model and GIS

In our previously built TSDM, integration between SD, CA, and GIS was accomplished. However, GIS only played a role as spatial visualization throughout the model, and did not affect the final simulation results. In the transition rules of the CA model in TSDM, the cell state $S_{t+1}$ at time $t+1$ is determined by $S_t$ (the central cell state at time $t$), $N_t$ (the neighborhood cell state at time $t$), and $SD_{t+1}$ (the influence on the central cell by SD model at time $t+1$). This can be calculated as $S_{t+1} = f(S_t, N_t, SD_{t+1})$.

However, in practical applications, the land-use situation in certain areas is often affected by mandatory changes from the government at certain time points. One such example is the establishment of the Xiongan New Area in Hebei Province. The impact of sudden policy changes on regional spatial patterns cannot be simulated by integrating the traditional CA model with GIS. Therefore, in this paper, the sudden policy is spatialized using the GIS platform and is then imported to the CA model to influence land-use changes. Based on this, formula (1) is extended as follows:

$$S_{t+1} = f(S_t, N_t, SD_{t+1})$$

As shown in Fig. 1, in the ETSDM, the SD model starts to run. Then, the CA model is controlled by the central cell state, the neighborhood cell state, and the macro-factors simulated from the SD model. Simultaneously, the CA feeds the results back into the SD model to promote the next-moment simulation. This process is performed iteratively until the set time point is reached (Liu et al., 2017). During operations, when the model runs to a certain time point, the model is suspended and the GIS spatialization policy data are imported into the model to become a part of the CA transition rules. Then, the model continues to run. Likewise, if a momentary result is of interest during the simulation process, the model can be paused and the current results can be exported as standard formats to the related GIS software for further operational analysis. The model continues to run until the simulation reaches the set time point, at which point it stops. In the ETSDM, during model operation, the model can be interrupted at any time point, as many times as required. Additionally, standard vector data can be imported or exported at any time, a characteristic that increases the current situation of the simulation to effectively extend the integration mechanism with GIS.

3.3. Extended neighborhood rules in the CA model

The neighborhood is one of the most important components in a CA model; it determines the cell range and cell number that affect the central cell. Traditional neighborhoods in the CA model are the Moore neighborhood and Von Neumann neighborhood (White and Engelen, 2000). Although some literature has extended the neighborhoods (Chen et al., 2014; Liao et al., 2016; Shi and Pang, 2000; Yufeng et al., 2014), they generally enlarge or reduce the range of neighborhoods. In traditional neighborhoods and some extended neighborhoods, all neighborhood cells are treated the same and are not distinguished in nature. In the Von Neumann neighborhood, only the cells adjacent to the central cell edge are considered, while in the Moore neighborhood, the cells adjacent to the central cell point and edge are both taken into account. As a result, if the Von Neumann neighborhood and Moore neighborhood are comprehensively considered, what is the result? In fact, according to the objective experience of the real world, we can also determine that the neighborhood cells will have different influences on the central cell with the different contact areas. Thus, the two neighborhood types should be distinguished, rather than simply containing the cells adjacent to the central cell point (the Moore neighborhood) or not containing (the Von Neumann neighborhood).

A “Square + Circle” neighborhood is proposed in this paper (see Fig. 2); such neighborhoods are unbiased in all directions. In a “Square + Circle” neighborhood, the effect intensity of neighborhood cells on the center cell depends on the effect weight of the neighborhood cells in the circular region, which can effectively distinguish between different neighborhood cells and offset the insufficiencies of the Moore and Von Neumann neighborhoods. Furthermore, in order to facilitate calculation and eliminate the interference of dimensions, the effect weight of the neighborhood cells is normalized. The formula of the effect weight $E_n$ can be shown as follows:

$$E_n = \frac{S_{n}}{S_{c}}$$

where $S_{n}$ is the effect weight of the circular neighborhood cell (the cell covered by the circle in Fig. 2 except for the central cell), and $S_{c}$ is the effect weight of the square cell (the normal neighborhood cell used in the Moore neighborhood).

3.4. Simulation of land-use policy scenarios

In this paper, the following three development scenarios were constructed: (1) under conditions in which Beijing, Tianjin, and Hebei Province develop independently (following existing trends); (2) under the coordinated development of the BTH region; and (3) under the establishment of the Xiongan New Area. In this study, only changes in cropland, woodland and grassland, and built-up land were simulated.
and analyzed. Water body was not taken into account.

1. Beijing, Tianjin, and Hebei Province independent development

Assuming that Beijing, Tianjin, and Hebei Province followed existing trends and continued to develop independently without affecting one another, there was also no data exchange among the three regions. Scenario 1 was used as a blank control group for the next two scenarios.

1. Coordinated development of the BTH region

In this scenario, we assumed that the BTH region developed coordinately. We aimed to observe possible changes in spatial land-use patterns after the implementation of national macro-policy. Additionally, we aimed to realize the display, based on macro-data or textual descriptions to visualize spatial results.

In 2014, Chairman Xi proposed BTH coordinated development, which is aimed at creating a new capital economic circle and promoting the innovation of regional development. The principal goal of BTH coordinated development is to develop the Beijing, Tianjin, and Hebei Province as a whole, with the purpose of releasing non-capital functions and solving the “big city disease” problem for Beijing.

In this study, the Beijing, Tianjin, and Hebei Province were considered as a whole for conducting spatial simulations. With respect to macro-quantities, the population, GDP, and other factors were overall considered in the SD model, which neglected data exchange and flow between the three regions. Indicators and resources were uniformly regulated in the macro-dimension, breaking the administrative line and ignoring the microscopic control.

1. Influence of the Xiong New Area on the BTH region development

On April 1, 2017, the Communist Party of China Central Committee and State Council decided to establish the Xiong New Area, which mainly covers Xiong County, Rongcheng County, and Anxin County. The Xiong New Area aims to reduce population pressure and excessive urban expansion in Beijing. It is designed to load the non-capital functions of Beijing and adjust and optimize the urban layout and spatial structure of the BTH region. The starting area of the Xiong New Area will cover approximately 100 km² and will expand to 200 km² in the medium-term. The control area of the Xiong New Area will be approximately 2000 km² in the long-term. Based on this, in order to more intuitively and rapidly simulate the impact of the Xiong New Area, we assumed that the established Xiong New Area covered 2000 km², including the Baoding urban area (Fig. 3).

The model began by simulating operations according to the BTH region coordinated development from 2013. During the operation to 2017, the policy planning area was vectorized in GIS. Then, the proposed Xiong New Area was loaded into the model to push the model to continue. The above operation aimed to simulate the temporal and spatial effects on the whole region affected by the sudden national policy which delineated a certain range on the map.

4. Simulation result

4.1. Simulation accuracy

To ensure the validity of the model and the authenticity of the simulation results, reliability verification is needed before the model can be used to make future development scenario predictions (Li and Liu, 2006). In this study, the simulation accuracies of the above four regions were verified, while land-use data for the four regions for 1995 were used to fine-tune and test the model parameters. The data for 2005 were used to further validate the adjusted model.

To effectively validate the accuracy of the simulation results, a point by point comparison method was adopted to calculate the overall accuracy of the simulation results. At the same time, the Kappa coefficient (Congalton, 1991) was employed to verify the consistency of the simulation results. The Kappa coefficient is widely used to evaluate accuracy. Compared with overall accuracy, the Kappa coefficient more accurately represents the simulation results, because of the full consideration of the proportion of various pixels (Sakieh et al. 2015). After the calculation, the overall simulation accuracies of all four areas were greater than 76.82%, and the Kappa coefficients were all greater than 0.6175 (see Table 2). The results show that the ETSDM has better overall accuracy, as does the Kappa coefficient. Of course, because of remote sensing image quality and interpretation effects, the simulation accuracy will be affected to different degrees. Good simulation results show that the ETSDM can be used for further scenario simulation studies.

4.2. Land-use policy scenario prediction for the BTH region

In the past nearly two decades in the BTH region from 1995 to 2013, the expansion of built-up land was very obvious, especially in the major cities, such as Beijing, occupying a lot of cropland, and woodland and grassland. How to control the over-expansion and achieve a win-win mode between economy and environment is a challenge for the government. The detailed values of the main variables used in the SD model are listed in Appendix B. Meanwhile, the Scenario 2 used the same values as the Scenario 3 due to the same study area.

4.2.1. Scenario 1: Beijing, Tianjin, and Hebei Province independent development

Table 3 and Fig. 4 presents the land-use changes for Beijing, Tianjin, and Hebei Province from 2013 to 2030. It was obvious that the built-up land areas in the above three regions increased to different degrees. The built-up land area for Beijing increased by 1791.44 km² and that of the woodland and grassland also increased by 247.4 km², which was compensated for by decreases in the cropland. Increases in the construction regions occurred mainly in the Fangshan District, Daxing District, Changping District, Shunyi District, and Tongzhou District, and these suburban areas became part of the central urban district. The built-up land area for Tianjin increased by 1055.32 km², but the crop-land, and woodland and grassland reduced correspondingly. The built-up land changed mainly in the central urban area, Wuqing District, and Binhai New District. The built-up land area for Hebei Province increased by only 1882 km², mainly in Shijiazhuang, Baoding, Tangshan, Handan, and Xingtai. However, woodland and grassland increased by 5877 km², with a large decrease in the cropland to compensate. This may have occurred because of a serious shortage in water resources in recent years, which was related to the relevant fallow and water-saving policy, leading to a large number of cropland changes that increased the water-saving woodland and grassland. In other words, by 2030, the whole built-up land area would increase to more than 30,000 km², and cropland area would decrease by more than 10,000 km² under the scenario for the Beijing, Tianjin, and Hebei Province independent development.

4.2.2. Scenario 2: the coordinated development of the BTH region

By comparing the land-use simulation patterns for the BTH region in 2030 with the real patterns in 2013, we observed that the central urban areas of Beijing, Tianjin, Shijiazhuang, Tangshan, Baoding, Xingtai, and Handan over-expanded, and the cropland and green belt in the urban-rural fringe were occupied by urban built-up land because of the effects of central urban convergence and traffic factors, coupled with continuous population growth (Fig. 5). Because of the rise of high-efficiency projects (such as real estate), individuals neglect and underestimate issues of public interest (such as the ecological value and food security provided by cropland and green belts in the urban-rural fringe), which leads urban centers to develop into larger urban centers. This undoubtedly exacerbates urban environmental problems, water
shortages, food security issues, and other problems, and has a very serious effect on urban sustainable development.

Under Scenario 2, the built-up land area in Beijing increased by 1491.4 km², which was approximately 300 km² less than in Scenario 1. The cropland area decreased by 1539 km² and the woodland and grassland area increased by 102.96 km². Under Scenarios 1 and 2, the development in Tianjin was approximately the same. The built-up land area in Hebei Province increased by 4417 km², a larger increase than in Scenario 1. At the same time, compared with Scenario 1, cropland area was significantly reduced, by 11,644 km² (see Table 4). Because of the coordinated development of the BTH region, some industries having non-capital functions, such as manufacturing and regional wholesale markets, were moved to Tianjin or Hebei Province, resulting in built-up land area increase in Tianjin and Hebei Provinces. Thus, the expansion rate of Beijing slowed, and the non-capital functions were effectively eased, protecting the limited available cropland, and woodland and grassland in Beijing and promoting urban sustainable development.

4.2.3. Scenario 3: the influence of the Xiongan New Area on the BTH region development

Similar to the results for the coordinated development of the BTH region (Section 4.2.2), built-up land conversion occurred mainly in
Beijing, Tianjin, Shijiazhuang, Tangshan, Baoding, Xingtai, and Handan, largely because of population and economic increase. To easily observe the development and change of the Xiongan New Area, the operation was intercepted to obtain operation data for 2020, 2025, and 2030 using data interaction with GIS. To clearly show land-use changes, Baoding in Hebei Province was clipped. It could be seen that, from 2013 to 2030, after nearly 20 years of development, the "cluster" of Xiong County, Rongcheng County, Anxin County, and Baoding urban area had begun to take shape (Fig. 6). The Xiongan New Area is of great practical significance for easing Beijing pressure and adjusting and promoting the development of the BTH region. Of course, the Xiongan New Area is a millennium strategy and national event, which cannot be completely developed over a short period of time. In this study, in order to highlight the timeliness of the policy and increase the visibility of the simulation results, the development pace of the Xiongan New Area was sped up and the initial development area was also increased.

5. Discussion

5.1. Comparison the "Square + Circle" neighborhood with the traditional neighborhoods

The simulation accuracies under the improved "Square + Circle" neighborhood, Moore neighborhood, and Von Neumann neighborhood for the above four regions from 1995 to 2013 were calculated and compared. In this study, to simplify calculation and facilitate operations, we used only the effective area occupied by the circular neighborhood cells as the weight. Because of the refinement of neighborhood
cells, the simulation accuracies for Beijing, Tianjin, Hebei Province, and the BTH region were improved at different levels (Table 5), and the simulation effect of the model was refined. The extended “Square + Circle” neighborhood is not primarily intended to improve simulation accuracy, but rather to increase the practical meaning of the simulation. If the weight is combined with the actual application to calculate, it will have more practical significance.

5.2. Impacts on Beijing under a variety of development scenarios

With respect to either the coordinated development of the BTH region in 2014 or the establishment of the Xiongan New Area in 2017, an important objective is to ease non-capital functions and reduce the expansion rate of urban built-up land for Beijing. The policies are aimed at rebuilding Beijing’s capital function and constructing a green, ecological, and livable city.

In the above three development scenarios, changes in various land-use types in Beijing were shown in Fig. 7. It could be seen from the figures that the coordinated development of the BTH region and establishment of the Xiongan New Area curbed the built-up land expansion of Beijing to some extent and protected some cropland, woodland and grassland in the long-term development process. This may have occurred because of the establishment of the Xiongan New Area, which eases some non-capital functions in Beijing. However, because of population growth and economic development, urban land-use expansion is very complex. In the future development of Beijing, because of land-use demands and the driving of economic benefits, the central urban area will continue to expand, and the government decision-makers will need to develop more stringent and effective policies.

Table 4
Land-use areal changes for Beijing, Tianjin, and Hebei Province from 2013 to 2030 under Scenario 2 (km²).

<table>
<thead>
<tr>
<th></th>
<th>Cropland</th>
<th>Woodland and grassland</th>
<th>Built-up land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing 2030</td>
<td>2128.00</td>
<td>8562.00</td>
<td>5431.00</td>
</tr>
<tr>
<td>Increment</td>
<td>−1539.00</td>
<td>102.96</td>
<td>1491.40</td>
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<tr>
<td>Tianjin 2030</td>
<td>5858.00</td>
<td>432.00</td>
<td>3972.00</td>
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<td>Increment</td>
<td>−999.76</td>
<td>−52.08</td>
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<tr>
<td>Hebei 2030</td>
<td>82475.00</td>
<td>77,517.00</td>
<td>23,179.00</td>
</tr>
<tr>
<td>Increment</td>
<td>−11,644.00</td>
<td>6060.00</td>
<td>4417.00</td>
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</table>

Fig. 5. Land-use changes under the BTH region coordinated development from 2013 to 2030.
that can more effectively curb the further expansion of Beijing and achieve sustainable and green urban development.

5.3. Policy implication

With the rapid economic growth, unbalanced development among cities has led to serious problems. The primary task of the coordinated development of the BTH region is to ease non-capital functions and solve the "big city disease" problem for Beijing. At the same time, the coordinated development means to drive the regional overall development. The establishment of the Xiongan New Area is intended to load the non-capital functions and promote the development of Hebei Province, forming a harmonious city group. Under the coordinated development of the BTH region and the establishment of the Xiongan New Area, we can see that the pace of expansion in Beijing has slowed and some major cities in Hebei Province have rapidly developed from 2013 to 2030. Once the construction of Xiongan New Area is completed, it will promote the industrial transformation and upgrading of Hebei Province and change the national economy structure which the economy in the south is much better than that in the north.

6. Conclusions

In this study, the ETSDM is used to implement temporal and spatial interoperability with GIS, effectively solving the question to use macro-data or text description policy to visualization of real application. Additionally, the method also achieves the loading problem of the sudden policy in simulation process. By extending the integration mechanisms with GIS, the model realizes effective interaction and data feedback between the temporal and spatial dimensions, allowing for the implementation in the simulation of sudden policy changes under different conditions. This adds authenticity and timeliness to the simulation. At the same time, the types of neighborhood cells are refined by extending the "Square + Circle" neighborhood, and simulation accuracy and authenticity are improved to a certain extent.

Through the study of the BTH region under the three development scenarios, we found that the implementation of the BTH region coordinated development strategy was conducive to promoting the optimization of the regional land system. Meanwhile, the establishment of the Xiongan New Area eased the non-capital functions of Beijing. By attracting regional population and gathering industries, it is conducive to improving the stability of the BTH system and alleviating urban pressures in Beijing. This has played a certain role in slowing the pace of urban expansion in Beijing, reducing ecological pressure, and promoting balanced development among regions to create a world-class "capital circle."

Land-use changes are complex changes affected by different natural

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Table 5

<table>
<thead>
<tr>
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<tr>
<td></td>
<td>Overall accuracy</td>
<td>Kappa coefficient</td>
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<tr>
<td>Beijing</td>
<td>Moore</td>
<td>83.14%</td>
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<td></td>
<td>Von Neumann</td>
<td>83.09%</td>
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<td>Tianjin</td>
<td>Moore</td>
<td>75.95%</td>
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<td>Von Neumann</td>
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<tr>
<td>Hebei</td>
<td>Moore</td>
<td>82.08%</td>
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<td></td>
<td>Von Neumann</td>
<td>81.93%</td>
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<tr>
<td>BTH region</td>
<td>Moore</td>
<td>81.36%</td>
</tr>
<tr>
<td></td>
<td>Von Neumann</td>
<td>81.28%</td>
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</table>

Fig. 6. Land-use changes for Baoding in Hebei Province from 2013 to 2030 under the influence of the Xiongan New Area.
and social factors on varying temporal and spatial scales. In this study, considering the data availability, only some main driving natural and social factors were taken into account to simulate land-use changes. Complete, in-depth, and thorough research has more authenticity. Therefore, in our next work, the natural and social indexes affecting land-use changes will be fully considered. Additionally, it will be necessary to refine the neighborhood rules by weight, a process that has practical meaning.

Acknowledgements

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Appendix A. The main equations in SD model

In SD model, the feedback and causality between variables are quantitatively expressed by equations. In this paper, there mainly contain three key elements: population, GDP, and built-up land.

The added value from time $t$ to $t+1$ for population $P_{inc,t,t+1}$ can be expressed as follows:

$$P_{inc,t,t+1} = P_t \times (R_{nat} + R_{mec})$$

where $P_t$ is the population at time $t$; $R_{nat}$ is the growth rate for natural changes; and $R_{mec}$ is the growth rate for non-natural changes.

The added value from time $t$ to $t+1$ for GDP $G_{inc,t,t+1}$ can be calculated as (Tian et al., 2016):

$$G_{inc,t,t+1} = G_t \times R_{gdp}$$

where $G_t$ is the GDP value at time $t$; and $R_{gdp}$ represents the GDP growth rate.

Meanwhile, the added area from time $t$ to $t+1$ for built-up land $L_{inc,t,t+1}$ can be denoted as follows:

$$L_{inc,t,t+1} = C_{pop} \times P_{inc,t,t+1} + C_{gdp} \times G_{inc,t,t+1}$$

where $C_{pop}$ is the influenced index by the population on the built-up land area; and $C_{gdp}$ is the influenced index by the GDP on the built-up land area.
Appendix B. The values of variables for the main equations in Appendix A for the four study regions

<table>
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<tr>
<th></th>
<th>Beijing</th>
<th>Tianjin</th>
<th>Hebei</th>
<th>BTH region</th>
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<tbody>
<tr>
<td>$R_{att}$</td>
<td>0.0024</td>
<td>0.0027</td>
<td>0.0067</td>
<td>0.0040</td>
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<td>$R_{wuc}$</td>
<td>0.0246</td>
<td>0.0193</td>
<td>0.0007</td>
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<td>$R_{gdp}$</td>
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<td>0.1265</td>
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<tr>
<td>$C_{pop}$</td>
<td>0.6607</td>
<td>1.0130</td>
<td>7.1680</td>
<td>2.6700</td>
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<tr>
<td>$C_{gdp}$</td>
<td>0.0420</td>
<td>0.0750</td>
<td>0.1580</td>
<td>0.1080</td>
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References


