Scenes simulation of dynamic growth in Jinan urban based on SLEUTH model

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Abstract. Jinan City, with rapid urban growth and prominent ecological environmental pressure, was selected for the research area. We used SLEUTH model to simulate scenes of urban dynamic growth. On the basis of the actual situation of Jinan urban area, this paper presents three urban growth models to reveal the trend of urban growth under different types of land protection intensity. The results show that scene 1 was based on a hypothesis that the intensity of urban development remained basically unchanged in the scene of future urban growth and changed with the form of simulation. At this time, urban land use growth was fast and the urban expansion was mainly marginal growth; Scene 2 increased the degree of water protection to 80%, and the degree of farmland and woodland protection to 50%, which effectively controlled the urban growth; Scene 3 increased the degree of cultivated land and woodland protection to 80% and 90% respectively, resulting in a significant deterrence of the urban growth trend. The study proved the applicability of the SLEUTH model to urban growth prediction in China, and provided a theoretical basis for urban planning of Jinan.

1. Introduction

In recent years, China has entered a stage of rapid economic and industrial development, in which the urban area and population continued to expand, resulting in numerous urban diseases and urban construction contradictions and other issues. Accurate prediction of urban dynamic growth can provide a scientific basis for municipal managers to formulate urban planning policies. Urban growth prediction models include neural network model, non-grid CA model, probability and statistics model as well as SLEUTH model[1]. Among the above species, SLEUTH model is one of the most commonly used methods in the process of urban growth simulation and using simple local rules to simulate the complex structure of urban growth space based on CA theory. The model comprises two modules, UGM (urban growth model) and DLCM (dilatation land cover model)[2]. This paper only studies the spatial growth state of Jinan urban area, so the input file needs to include five input layers: Urban, Transportation, Slope, Excluded, Hillshade[3]. Five growth factors are set up in the model, which is diffusion coefficient, reproduction coefficient, ductility coefficient, slope resistance coefficient and road gravity coefficient[4, 5]. Four growth rules are proposed, which are spontaneous growth, new center growth, edge growth and road gravity growth[6]. The calibration of the model is the fundamental part. It usually requires three parts: an initial calibration, fine calibration and final calibration. Then the final five growth factors are determined, and set up three scenes by adjusting the urbanizability of different land use types. This paper provides decision-making reference for regional land regulation and urban planning.
2. Data and research methods

2.1. Research area
Jinan is located in the central part of Shandong Province. Its geographical position is between 116°11' and 117°44' E and 36°02' and 37°31' N. The total area of Jinan is 8177 km². The study area is mainly the urban area with rapid economic and population development in recent years (including six districts: the city center district, Licheng district, Lixia district, crossover district, Huaiyin district and Changqing district), covering an area of 3357 km².

2.2. Data sources and preprocessing
The basic data used in the SLEUTH model are shown in Table 1.

| data type    | age      | Data name            | Source of information            | scale |
|--------------|----------|----------------------|----------------------------------|-------|
| raster data  | 1990     | landsat 4-5 TM       | Geospatial data cloud            | 30m   |
|              | 2001     | landsat 4-5 TM       | Geospatial data cloud            | 30m   |
|              | 2008     | landsat 4-5 TM       | Geospatial data cloud            | 30m   |
|              | 2015     | Landsat 8 OLI_TIRS   | Geospatial data cloud            | 30m   |
|              | 2018     | Jinan DEM digital elevation data | Jinan Hydrology Bureau | 10m   |
| image data   | 2006-2020| Jinan master plan map| Jinan Municipal Planning Bureau  | 1:50000|
| vector data  | 2000     | Electronic map of Jinan | Jinan Municipal Planning Bureau  | 1:50000|
|              | 2012     | Electronic map of Jinan | Jinan Municipal Planning Bureau  | 1:50000|

Supported by ENVI, TM images in 1990, 2001, 2008 and OLI images in 2018 were corrected by radiometry and geometry. Then, the images were supervised and classified by visual interpretation and Google Earth image contrast, and the raster-to-vector processing was carried out. Finally, the ARCGIS platform was used to extract the road data of 2000 and 2012 from the 2000-2020 Jinan urban planning map and the electronic map of 2000 and 2012.

2.3. Model data preparation
From the historical remote sensing images, the data were extracted by ENVI software and then obtained the urban area vector data of Jinan in different periods (1990, 2001, 2008, 2018). Two traffic layers were extracted and transformed into a 30 m resolution raster image by ARCGIS. The data were re-classified into binary graph (expressed by 1, 0). From the DEM data of the study area, the slope and mountain shadow map are generated, and the 3 layers are excluded. Finally, all layers are translated into GIF format and named uniformly.
2.4. Model calibration

The calibration process of the model is actually a comparison between the real urban growth state simulated in the past year and the growth state simulated by the model. The model enumerates 13 basic model indices in comparison, but it is difficult to select the exact value of 5 growth factors successfully if 13 model indices are compared in one calibration process. The Lee-Salee shape index, which is the spatial matching degree between the growth of the model and the actual growth of the city, is widely used for reference in the study of the evaluation parameters of the model. The formula is

$$S = \frac{A \cap B}{A \cup B},$$

in which A represents the simulated area of the city and B represents the real area of the city\[^7\].

To sum up, the Lee-Salee shape index is chosen as the calibration parameter of the model.

### Table 2. Calibration of SLEUTH model parameters

| Model parameter       | Coarse calibration | Precision calibration | Final calibration | Final value |
|-----------------------|--------------------|-----------------------|-------------------|-------------|
|                       | Range step         | Range step            | Range step        |             |
| Dispersion_coefficient| 1−100 25           | 1−25 5                | 1−6 1             | 1           |
| Breed_coefficient     | 1−100 25           | 25−50 5               | 25−35 1           | 33          |
| Spread_coefficient    | 1−100 25           | 75−100 5              | 95−100 1          | 99          |
| Slope_coefficient     | 1−100 25           | 1−50 10               | 1−21 3            | 3           |
| Gravity_coefficient   | 1−100 25           | 1−75 15               | 36−46 2           | 46          |
| Monte-carlo_coefficient| 4 8                | 10                    |                   |             |
| Lee-Sallee            | 0.60103            | 0.60043               | 0.60145           |             |

Through the operation of three-stage calibration, the Lee-salt index increased to 0.60145 after the final calibration, and the shape index was above 0.6 during the three-stage calibration, indicating that the calibration results were good, but not the best. Relevant literatures show that the size of shape index is influenced by the area of the region, the resolution and accuracy of image data, the time interval of historical data and the time of initial historical data and other factors\[^8\].
3. Prediction of urban dynamic expansion in Jinan urban area by 2035

3.1. Scene setting
Exclusion layer can generate different growth scenes by setting the urbanization probability of different land use types, and can also set the scope of the Exclusion layer according to government planning. The input format of the SLEUTH model mentioned above is an 8-bit grayscale gif image. The exclusion layer is set between 0 and 100, and the default assignment value is less than 100 if it is greater than 100. The more the assignment is, the higher probability of urbanization. In the part of land use status, the land use types of the study area are divided into six categories, namely urban, rural, cultivated land, woodland, water and industrial land. According to the actual situation of Jinan urban area and the classification results of land use supervision, this paper puts forward three urban growth models.

(1) Free growth scene: to set the protection probability of the water part to 80%, the other part of the free growth according to the growth coefficient.

(2) Basic protection scene: refer to the protection of ecological land and basic farmland from the point of view of appropriate control of urban growth. The study area will be part of the water protection probability set to 100%, cultivated land and forest protection probability set to 50%, rural protection probability set to 30%, industrial land set to 20% protection.

(3) Strict protection scene: means to strengthen the protection of ecological land in the study area, setting the water part as 100% protection probability, the cultivated land as 80% protection probability, the woodland as 90% protection probability, the rural area as 50 protection probability, the industrial land as 30% protection probability.

3.2. Prediction results of Jinan urban morphology expansion under different scenes
This paper predicts the future urban spatial form of Jinan urban area by simulation period in 2035.
(1) Free growth scene:
As can be seen from Figure 3, urban growth in the context of free growth showed a state of disorderly spread, especially in urban areas within urban boundaries, which will aggravate the ecological pressure of urban areas. From the value of growth coefficient, we can see that the spread coefficient has been stayed in the dominant position, and the road gravity coefficient has been gradually increased, which also explained the impact of Road Development on urban growth.

(2) Basic protection scene:
As can be seen from Figure 3, we can see that under the basic protection scene, the speed of urban growth has been hindered. Compared with the spatial morphology, the urban sprawl in this scene was smaller than that in the free growth scene. In this situation, the area index in 2035 was smaller than the area index under the free growth scene. From the growth coefficient, it can be seen that the spread coefficient was still in the dominant position, and the road gravity coefficient increased gradually while the other indexes do not change significantly.

(3) Strict protection scene:
As can be seen from Figure 3, under the strict protection scene, the speed of urban growth was significantly reduced because of the increased protection of various ecological lands. In terms of spatial morphology, this scene of urban expansion and free growth, as well as the basic protection trend of the scene were less spread speed. The area index in 2035 was smaller than that in the other two scenes. It can be seen from the value of the growth coefficient that the spreading coefficient was still in the dominant position, and the road gravity coefficient was gradually increased, while the other exponents did not change significantly, and the change trend of the growth coefficient was basically the same in the three scenes. The specific area growth trend and the change of the growth line array are shown in Table 3.

| Table 3. Coefficient changes in 2035 under different scenes |
|------------------------------------------------------------|
| area           | diffus | spread | breed | slp_res | rd_grav |
| scene1        | 129188.6 | 1.0     | 87.4  | 30.8    | 2.7     | 50.3   |
| scene2        | 123045.9 | 1.0     | 88.3  | 31.1    | 2.5     | 50.2   |
| scene3        | 113806  | 0.9     | 80.1  | 28.0    | 4.3     | 49.4   |

4. Conclusion
Comparing the urban growth forecasts of the above three scenes, we draw the following conclusions. At first, urban growth area was expanding continuously, but with the increasing probability of land protection, the growth rate was decreasing. In addition, the change trend of the growth coefficient under the three scenes was basically the same, which was the result that the spreading coefficient was dominant and the reproduction and the road gravity coefficient were supplementary. The three scenes basically complied with Jinan's planning policy. Among them, the growth rate of the southern mountainous area is relatively small, which conforms to the "south control" ecological protection strategy in Jinan city planning; the urban villages and enterprises in the urban area were also partially urbanized, reflecting the "excellent" strategy; the urban area mainly orientated to the East and west, and the three scenes of the study area basically realized urbanization to the west. The development strategy of "westward" and "East extension" was presented. In the free growth scene, the urban area grew faster, and the impact on the ecological environment was often neglected. In the basic protection scene and the strict protection scene, the protection of cultivated land and woodland was emphasized. However, the urban area of Jinan as the center of Jinan reflected the development of Jinan city. Strict protection scenes had higher restrictions on the future development of urban areas, which was not conducive to the extension process of urban areas. Therefore, selecting the basic protection scenes can better continue the footprint of urban space development in Jinan, and making a more scientific prediction of Jinan urban areas from the future to 2035.

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