ISSN: 2710-0723

Multi-scenario Prediction Simulation Analysis of Land Use in Weinan City based on the PLUS Model

Yiman Guo

Xi'an International Studies University, Xi'an710100, China

Abstract

Based on the Patch-generating Land use Simulation Model (PLUS), this paper comprehensively considers natural factors and socio-economic factors and selects seven driving factors. The spatio-temporal variation pattern and driving forces of land use in Weinan City from 2000 to 2020 were analyzed. Four scenarios, namely natural evolution, ecological protection, economic development and cultivated land protection, were set up to conduct a simulation analysis of land use in Weinan City in 2040.

Keywords

PLUS Model; Land Use Change; Multi-scenario Simulation; Weinan City.

1. Introduction

Land, as a key element in nature, is the most fundamental natural resource and material basis for human beings to maintain their own survival and development. People change the land use structure by transforming and utilizing the different attributes of the land to meet the requirements of social development. Land Use/Cover Change (LUCC) is one of the most significant changes in the terrestrial surface system. Land use/cover change is a complex process that is comprehensively influenced by natural, social, economic and technological conditions, significantly altering regional and even global ecosystems, and even threatening the sustainable development of human society.

Its research mainly focuses on change characteristics, driving factors, dynamic evolution, model simulation, sustainable utilization, etc. Setting up different scenarios to simulate land use changes is the basic basis for future land use planning and is of great significance for achieving regional social, economic and ecological harmony and stability [1].

In recent years, a large number of studies and experiments have been carried out on the theme of land use change simulation and prediction, with remarkable achievements. A large number of models have been developed and widely used to assist in decision-making. At present, there are mainly three types of land use change simulation models: quantitative prediction models, spatial prediction models, and coupled models [2]. Quantitative simulation models can predict the area of various types of land use in the future based on the current land use status, but they cannot predict their spatial distribution. Typical models include Markov Model[3], System Dynamics Model[4], grey model [5], etc. Spatial simulation models, with their excellent spatiotemporal dynamics, can simulate and predict the evolution process of the spatial pattern of land. Classic models of this type include CA(cellular automata) [6], MAS(multi-agent systems) [7], etc. Due to the lack of constraints or conditions for termination of operation, its simulation results cannot meet the macro laws of regional social, economic and population development. The coupled model adopts the method of coupling multiple models and combines the advantages of various techniques to overcome the inherent limitations of a single model [8]. The methods used in model simulation are classified into three categories: transition analysis strategy (TAS), pattern analysis strategy PAS), land expansion analysis strategy (LEAS). Representative models of TAS include logistic-CA [9], ANN-CA [10], CA-Markov [11], etc. PAS

ISSN: 2710-0723

representative models include FLUS [12], CLUE-S [13], etc. LEAS not only has lower requirements for mining algorithms than TAS, but also enhances the mining ability of the driving mechanism of land use change compared to PAS. The representative model is PLUS. The PLUS model simulates patch-level changes in multiple types of land use by exploring the potential driving factors of land expansion and change. Compared with other models, the PLUS model can achieve higher simulation accuracy and more similar landscapes.

In conclusion, this paper selects the PLUS model, which features higher accuracy, faster data processing speed and good adaptability, as the land use simulation model for research. Taking Weinan City as the research area, the spatio-temporal characteristics of land use from 2000 to 2020 were quantitatively analyzed by means of dynamic attitude and transfer matrix. Seven driving factors of land use change were selected comprehensively considering the regional social and economic conditions, natural geographical features and transportation network conditions. Four scenarios, namely natural evolution, ecological protection, economic development and cultivated land protection, were set up. The PLUS model was used to simulate the spatial distribution of land use in 2040. The differences in the simulation results of four scenarios were compared and analyzed to provide reference for the rational allocation of land resources in Weinan City.

2. Study Area and Research Data

2.1. Overview of the Study Area

As shown in Figure 1, Weinan City is located between 108°58 '-110 °35' east longitude and 34°13 '-35 °52' north latitude. The terrain is centered around the Wei River, with the north and south being higher, the middle lower, and the east and west open. The alluvial plain in the middle is the widest area of the 800-li Qin Plain. It has a temperate monsoon climate, with an average annual temperature ranging from 12.5℃ to 14.8℃. The total annual precipitation ranges from 489.6 to 795.0 millimeters. Weinan City is the most superior agricultural ecological zone in Northwest China and is known as the "Granary of Shaanxi".

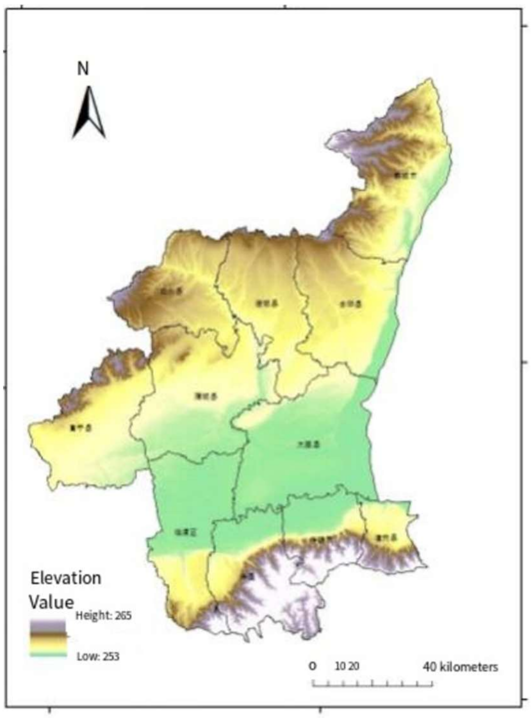

Figure 1. Administrative Division of Weinan City

ISSN: 2710-0723

2.2. Data Sources and Processing

The research dataset of the paper includes three periods of land use data in the study area in 2000, 2010 and 2020, as well as the driving factors required for constructing the PLUS model. Considering that land use change is influenced by natural, socio-economic and other aspects, the driving factors are combined with the actual situation of the study area and the principles of data quantification, accessibility and relevance. Seven factors, namely slope, annual average temperature, annual precipitation, population, gross domestic product (GDP), distance to the road and distance to the river, are selected and preprocessed through the ArcGIS platform. All samples are resampled to 30m×30m.

3. Research Methods

3.1. Dynamic Attitude and Transition Matrix

(1) The single dynamic attitude is used to calculate the quantity change of a certain type of land within a certain time range in the study area, and is usually represented by K. Its expression is:

$$K=\frac{U_b-U_a}{U_a}\times\frac{1}{T}\times 100\% \tag{1}$$

In the formula,$U_a$and$U_b$represent the areas of land categories at the initial and final periods, respectively, and T is the time interval between the two periods. The composite dynamic degree, defined as the annual rate of change for all land use types in the study area, is commonly represented as:"

$$L_c=\frac{\sum_{i=1}^{n}\quad \Delta L_{U_{i-j}}}{2\sum_{i=1}^{n}\quad \Delta LU_i}\times\frac{1}{T}\times 100\% \tag{2}$$

In the formula, $\Delta L_{U_{i-j}}$ represents the absolute value of the area transformed from the i land-use type to non-i type land, ΔLU_i denotes the area of the i land-use type in the initial period, and T is the time interval between the two periods.

The transition matrix is used to reveal the structural characteristics of each class and the direction of transformation between types. It can quantitatively describe the state transition and statistically analyze the inflow and outflow of each class. It can accurately and intuitively express the changes in land use types. The expression is:

$$P=\begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & A_{ij} & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{pmatrix} \tag{3}$$

In the formula,A denotes the area of land category;i and j epresent the land categories in the initial and final periods, respectively; and n is the number of land categories.

3.2. PLUS Model

The PLUS model integrates the Land Expansion Analysis Strategy (LEAS) and the Multi-type Random Seed CA Model (CARS), making up for the deficiencies of existing CA models in transformation rule mining strategies and land use dynamic change simulation strategies. At the same time, it incorporates the influence and driving effect of future planning policies on land use changes. This model mainly consists of a land quantity prediction module based on the

ISSN: 2710-0723

Markov model and a spatial distribution simulation module based on the improved CA model. Among them, the land quantity prediction module uses the existing land use data to predict the future quantity through the Markov model. The spatial distribution simulation module first uses LEAS to obtain the development probability of each land use based on the existing land use data, and then conducts a comprehensive analysis by using CARS in combination with the land use cost matrix, neighborhood weights, and the land use quantity under the current situation and scenario Settings. Ultimately, it realizes the allocation of the quantity of each type of land and obtains the spatial distribution map of the land use simulation.

3.2.1. Scenario Setting

Based on existing research experience and taking into account the historical land use transfer and change patterns and planning policies of Weinan City, four scenarios, namely natural evolution, ecological protection, economic development and cultivated land protection, are set up. Among them, the natural evolution scenario: It is based on the land use change pattern of Weinan City from 2010 to 2020 and predicts the land use demand in 2040 without changing the conditions. Economic development scenario Considering the vigorous promotion of urban construction in the "2024 Weinan Central City Urban Construction Project Plan", the quality of urban construction in the main urban area will continue to improve and its functions will be constantly refined. Based on the transfer from 2010 to 2020, it is assumed that the conversion of construction land to utilization types other than cultivated land will be reduced by 20%. The probability of converting cultivated land, forest land, grassland, water areas and unused land into construction land increases by 20%. Ecological protection scenario: The "14th Five-Year Plan for Forestry Development in Weinan City" aims to fully implement the national ecological civilization, ecological security, ecological forestry and people's livelihood forestry, expand the scale of forest resources, and enhance the carrying capacity of the ecological environment. On the basis of the transfer from 2010 to 2020, the conversion of forest land, grassland and water areas to other utilization types will be reduced by 30%, and the conversion of other land (excluding grassland) to forest land, grassland and water areas will increase by 30%. The scenario of farmland protection: The quality and quantity of basic farmland are related to national food security. Therefore, the simulation of land use change needs to incorporate the idea of farmland protection as a benchmark scenario. Considering the significant loss of cultivated land from 2010 to 2020, on the basis of the transfer from 2010 to 2020, the probability of converting cultivated land to other land use is reduced by 30%, and the probability of converting other land use (excluding construction land) to cultivated land is increased by 20%.

3.2.2. Markov Chain Method

Based on the historical transition probability matrix of Weinan City from 2010 to 2020, the respective transition probability matrices were established in accordance with the scenario setting requirements of natural development, ecological protection, economic development and cultivated land protection, and the number of each category in the study area under the four simulation scenarios in 2040 was predicted. The calculation formula is:

$$S_{t+1}=S_t p_{ij} \tag{4}$$

In the formula, S_{t+1} and S_t denote the land use states at times t and t + 1, respectively, and p_{ij} is the transition matrix from land category i to land category j.

3.2.3. Basic Parameter Settings

Before the CARS module based on the improved CA model simulates the spatial distribution of the three scenarios, the land use cost transfer matrix and neighborhood weights are set. The land use cost transfer matrix only includes the numbers 0 and 1. 0 represents non-convertible, and 1 represents convertible. The neighborhood weight parameter represents the expansion intensity of different land use types, reflecting the expansion capacity of each class under the influence of spatial driving factors. The calculation formula is as follows:

$$X_i = \frac{\Delta TA_i - \Delta TA_{min}}{\Delta TA_{max} - \Delta TA_{min}} \tag{5}$$

In the formula, X_i is the neighborhood weight parameter for a certain land category, ΔTA_i also denotes the change in that land category during the study period; ΔTA_{max} and ΔTA_{min} represent the maximum and minimum changes in the study period for the variable TA.

The neighborhood weight indicates the expansion intensity of each land use type and assists in decision-making the neighborhood effect generated by each land use type. The neighborhood weight values of each land use type can be modified as needed, within the range of [0,1]. The larger the value, the greater the neighborhood influence and the stronger the expansion ability. Based on the scenarios of natural evolution, economic development, ecological protection and cultivated land protection, and in combination with the actual land use quantity and current spatial distribution in the study area, this paper sets the land use cost matrix (Table 1) and neighborhood weights (Table 2). Among them, the neighborhood weights under the natural evolution scenario are obtained through calculation. The neighborhood weights in the remaining three scenarios were adjusted based on the scenario assumptions and with reference to existing research.

Table 1. 4 Land Use Change Transfer Matrix under one Scenario

Development scenarios	Land use type	Farmland	Forest land	Grassland	Water body	Construction land	Unutilized land
Natural evolution	Farmland	1	1	1	0	1	1
	Forest land	1	1	1	0	1	1
	Grassland	1	1	1	1	1	1
	Water body	1	1	1	1	1	1
	Construction land	1	1	1	0	1	1
	Unutilized land	1	1	1	0	1	1
Ecological protection	Farmland	1	1	1	1	1	1
	Forest land	0	1	0	0	0	0
	Grassland	0	1	1	1	0	0
	Water body	0	0	0	1	0	0
	Construction land	0	1	0	1	1	1
	Unutilized land	1	1	1	1	1	1
Economic development	Farmland	1	0	0	0	1	0
	Forest land	1	1	0	0	1	0
	Grassland	1	0	1	0	1	0
	Water body	1	1	1	1	1	0
	Construction land	0	0	0	0	1	0
	Unutilized land	1	1	1	1	1	1
Farmland protection	Farmland	1	0	0	0	0	0
	Forest land	1	1	1	0	1	1
	Grassland	1	1	1	1	1	1
	Water body	1	0	1	1	1	1
	Construction land	0	0	0	0	1	0
	Unutilized land	1	1	1	1	1	1

ISSN: 2710-0723

Table 2. Weights of each class neighborhood in four simulation scenarios

Scenario Category	Farmland	Forest land	Grassland	Water body	Construction land	Unutilized land
Natural evolution	0.6	0.1	0.3	0	1	0.4
Ecological protection	0.6	0.3	0.4	0.1	0.7	0.4
Economic development	0.6	0.1	0.2	0	1	0.2
Farmland protection	0.7	0.1	0.3	0	0.6	0.2

4. Result Analysis

4.1. Analysis of Overall Land Use Changes

By obtaining the land use transfer matrix of the study area (Table 3), area and its changes (Table 4), and dynamic attitude of changes (Table 5) through the ArcGIS platform, it can be known that cultivated land accounts for the main part of the study area, and the proportion reached 64% in 2000, 2010, and 2020. Overall, the trends of land use changes in the first and last ten years from 2000 to 2020 were opposite. In the first ten years, construction land increased significantly, while cultivated land and ecological land decreased significantly. In the following ten years, the construction land decreased while the ecological land increased significantly. Spatially, the most significant change in the land use type in the study area is construction land, and the main source of conversion is cultivated land.

Table 3. Land Use Transfer Matrix from 2010 to 2020

Land use type	Land use area from 2010 to 2020/hm^2						
	Farmland	Forest land	Grassland	Water body	Construction land	Unutilized land	In 2010, in total
Farmland	805606.29	2617.38	10012.86	5412.96	2390.04	972.54	827012.07
Forest land	4174.56	128057.49	1482.48	217.53	43.29	460.53	134435.88
Grassland	6518.52	827.37	209637	1987.83	36.18	1400.58	220407.48
Water body	3448.62	188.28	743.22	17961.93	384.21	1090.26	23816.52
Construction land	17527.32	261.18	252.81	22.95	60607.53	0.18	78671.97
Unutilized land	148.14	529.02	443.25	47.34	0.27	6593.67	7761.69
In 2020, in total	837423.45	132480.72	222571.62	25650.54	63451.52	10517.76	1292105.61

Table 4. Land Use Area and Its Changes in Weinan City from 2000 to 2020

Land use type	2000		2010		2020	
	Area/hm^2	Ratio/%	Area/hm^2	Ratio/%	Area/hm^2	Ratio/%
Farmland	837415.17	64.81	827073.27	64.0	837509.31	64.80
Forest land	132474.78	10.41	134510.58	10.41	132570.27	10.26
Grassland	222606.72	17.23	220448.88	17.06	222653.79	17.23
Water body	25635.24	1.98	23903.82	1.85	25661.88	1.99
Construction land	63461.79	4.91	78673.86	6.09	63465.21	4.91
Unutilized land	10510.56	0.81	7770.42	0.60	10517.76	0.81

ISSN: 2710-0723

Table 5. Dynamic Attitude of Land Use Change in Weinan City from 2000 to 2020

Land use type	Land use dynamic state/%			
	2000-2010		2010-2020	
	Single index	Composite Index	Single index	Composite Index
Farmland	-0.12	0.13	0.13	5
Forest land	0.15		-0.14	
Grassland	-0.10		0.10	
Water body	-0.68		0.74	
Construction land	2.40		-1.93	
Unutilized land	-2.61		3.54	

4.2. Analysis of Driving Factors for Expansion of Various Types of Land Use

After superimposing the driving factors with the expansion data of various types of land use, the expansion factors were analyzed. According to the results, it can be known that the distance from the road, GDP and climatic conditions have the greatest impact on cultivated land. Cultivated land is mainly distributed in economically developed counties and districts with better natural conditions and far from the road, such as the foot of the Yulong Mountain Range and the Qinling Mountain Range, Hancheng and Pucheng. Regional gross domestic product, average annual temperature and annual precipitation have the greatest impact on forest land. The forest land is mainly distributed in the high-altitude areas in the north and south of Weinan (Yulong Mountain Range and Qinling Mountains). Among them, Fuping and Dali are known as the "Hometown of Persimmons in China" and the "Hometown of Jujubes in China". Although the altitude is relatively low, there are still large amounts of forest land distributed. The newly added grassland has a spatial distribution opposite to that of the water area. The grassland gradually decreases from the middle of the north-south direction, while the water area is mainly distributed in the middle part of Weinan, namely Dali and Pucheng. The growth of regional economy and population will inevitably lead to the expansion of urban construction land to other surrounding land. The construction land is mainly distributed in Fuping, Hancheng, Linwei and Dali, which have relatively high GDP levels.

4.3. Multi-Scenario Simulation Results

(1) Natural evolution scenario. Overall, except for the shrinking of cultivated land and water areas, all other types of land use have expanded. Among them, the expansion area of construction land was the largest, increasing by 51,500.97 hm^2, an increase of 81.15% compared with 2020. The cultivated land and water area decreased by 62,392.41 hectares and 2,420 hectares respectively. From a spatial perspective, the expanded construction land is mainly concentrated in the northern part of Chengcheng, the southwestern part of Hua County and Linwei.

(2) Ecological protection scenarios. Ecology is closely related to human beings and influences the production and lifestyle of society. In the south of Weinan City, there is the northern foot of the Qinling Mountains, and in the north, there is the ecological barrier of the Qiaoshan - Huanglong Mountain range. The plain area has characteristic economic forests, and the forest and grassland area is vast. The Weinan government attaches great importance to the development of forestry and ecological construction. Overall, in this scenario, except for the reduction in the area of cultivated land and unused land, the area of other land uses has increased. The area of cultivated land decreased by 2.26% compared with 2020, and the unused land decreased by 47.89%. Among the three types of land use - forest land, grassland and water area - water area saw the largest increase, rising by 33.89% to 8,698 hectares. Forest land increased by 3.42% and grassland by 2.43%. From a spatial perspective, the newly added forest

land is mainly concentrated in the five districts and counties near the northern foot of the Qinling Mountains. The newly added water areas are not only concentrated in the central and southern parts of Weinan City, but also increase significantly at the original rivers in the east.

(3) Economic development scenarios. With the continuous deepening of regional urbanization and the continuous improvement of infrastructure due to economic development, the priority development of construction land is set under the context of economic development. In this situation, except for the increase in the area of cultivated land and construction land, all other types of land use have decreased. The construction land increased by 25.44% compared with 2020, reaching 16,144.29 hectares. The cultivated land increased slightly, by 0.80%, reaching 6,710 hectares. The reduction in unused land was the largest, decreasing by 35.09% compared to 2020. The reduction in grassland area was the largest, decreasing by 12,133.62 hm^2. From a spatial perspective, the expansion area of construction land is mainly concentrated in the central part of Weinan City and the southern part of Linwei. This is closely related to the terrain and production level. The central plain has a low and flat terrain, a vast area, and a relatively good economic development. The newly added construction land expands outward along the main distribution area of the original construction land. However, in this scenario, the growth of construction land comes at the cost of a sharp decline in ecological land, seriously threatening the ecological construction of the study area.

(4) Scenarios of cultivated land protection. In this situation, the cultivated land area increased by 9,480.87 hm^2, but the forest land, grassland and water area all showed a decreasing trend. Among them, the forest land decreased by 8,135.1 hm^2, the grassland decreased by 11,739.42 hm^2, and the water area decreased by 1,697.04 hm^2. From a spatial perspective, the newly added cultivated land is mainly distributed in the southern part of Dali, the southern part of Linwei, and the southeastern part of Heyang. Dali and Linwei are important grain-producing counties in Weinan City. They are two of the four counties with the largest cultivated land area in Weinan city and also the major grain-producing counties in Shaanxi Province. Among them, Linwei District is located south of the northern foot of the Qinling Mountains, and the largest tributary of the Wei river, the Wei river, flows through the county. The natural environment is beautiful. It can be seen that under this scenario simulation, the area of cultivated land has increased, which has led to a vigorous expansion of construction land into forest land, grassland and water areas. However, sacrificing the ecological environment for regional economic development does not conform to the principle of sustainable development.

5. Conclusion

First, the land use status of Weinan City was analyzed based on the land use change model. Then, the PLUS model was used to simulate the land use change of Weinan City in 2040 by setting up four different scenarios. Finally, the results were analyzed and the following conclusions were obtained.

From 2000 to 2020, cultivated land, forest land and grassland were the main types of land use in Weinan City. During these ten years, except for the areas of construction land and forest land which increased, the areas of other types of land use all decreased. The conversion between various types of land use is intense. The expansion of construction land mainly comes from cultivated land. The main structure of land use change in Weinan City is unused land and construction land, among which the land use movement of construction land is the greatest.

Among the seven driving factors, climatic conditions and GDP have a strong driving force, which is related to the local production mode. The planting industry in Weinan City has a long history, and agricultural products and cash crops are the main sources of GDP. Human activities have a strong impact on the expansion of unused land and construction land. For instance, the

ISSN: 2710-0723

expansion of unused land is closely related to population density, while the expansion of construction land is closely related to the distance from roads.

Based on the analysis of the area change pattern, in the prediction of the evolution of each scenario, if no constraints are imposed, the areas of grassland, water areas and cultivated land will all show a shrinking trend. In the future, more emphasis should be placed on the intensification and modernization of crop production to achieve the goal of reducing the area of cultivated land without affecting production. Attention should also be paid to the protection of rivers and wetlands.

References

[1] Hu Jixi, Le Xianwen, Xu Yong The Impact of Multi-Scenario Land Use Change on Carbon Storage of Terrestrial Ecosystems Based on FLUS Model: A Case Study of Pingxiang, Jiangxi Province [J]. Soil and water conservation research, 2024, 31 (02) : 299-309. The DOI: 10.13869 / j.carol carroll nki RSWC. 2024.02.032.

[2] Li Fupeng, Han Hui, Yang Shuwen. Analysis of Land Use Change in Gansu Province from 2000 to 2020 and Multi-Scenario Simulation of Ecological Space Based on PLUS [J] Science Technology and Engineering, 2023, 23 (15): 6316-6326.

[3] Xie Xiangdong, Lin Xiaosong, Wang Ying, et al. Multi-scenario Simulation of Land Use in Nanchuan District, Chongqing City Based on PLUS Model [J]. Journal of Yangtze River Scientific Research Institute, 2023, 40 (06): 86-92+113.

[4] Fan Wenjie, Dai Xiaoai, Xie Yiru, et al. Prediction and Analysis of Land Use Change in Sichuan Province in the Next 10 Years Using the CLUE-S Model [J]. Science Technology and Engineering, 2022, 22 (07): 2641-2647.

[5] Cui Wanglai, CAI Li, Xi Henghui, et al. Ecological Security Evaluation and Multi-Scenario Simulation Analysis of Zhejiang Greater Bay Area Based on Land Use/Cover Change [J]. Acta Ecologica Sinica, 2022, 42 (06): 2136-2148.

[6] Wang Xiaolun, Liu Yan, Zhang Yu, et al Research and Prediction of Land Use/Cover Change in Western Jilin Province Based on CA-Markov Model [J] Science Technology and Engineering, 2021, 21 (19): 7942-7948.

[7] Sun Qinke, Zhou Liang, Tang Xianglong, et al. The Impact and Prediction of Oasis Urban Expansion in Arid Areas on Cultivated Land Space: A Case Study of the Hexi Corridor Region [J]. Journal of Natural Resources, 2021, 36 (04): 1008-1020.

[8] Zhang Xiaorong, Li Ainong, Nancy, et al. Multi-scenario Simulation of Land Use Change in the China-Pakistan Economic Corridor Based on the Coupling of FLUS Model and SD Model [J] Journal of Earth Information Science, 2020, 22 (12): 2393-2409.

[9] Wang Tian, Yan Jinfeng, Qiao Haiyan. Kuala Lumpur, Malaysia, the city land use change characteristic analysis and prediction [J]. Journal of soil and water conservation bulletin, 2020, 40 (5) : 268-275 + 341. DOI: 10.13961 / j.carol carroll nki STBCTB. 2020.05.039.

[10] Yan Yanghan, Guo Zijian, Wang Wenyuan, et al. Research on the Changes and Prediction of Port City Landscape Pattern Based on ANN-CA Model: A Case Study of the West Coast Area of Jiaozhou Bay [J]. Resources and Environment in the Yangtze River Basin, 2020, 29 (07): 1507-1514.

[11] Qi Lulu, Li Xiuxia, Li Hui. Research on Prediction of Urban Construction Land Scale Based on Constrained SD Model: A Case Study of Siping City, Jilin Province [J]. China Agricultural Resources and Regional Planning, 2020, 41 (01): 234-241.

[12] Song Shixiong, Liang Xiaoying, Chen Hai, et al. Simulation Research on Abandoned Farmland Based on Multi-Agent and Land Conversion Model: A Case Study of Mizhi County, Shaanxi Province [J]. Journal of Natural Resources, 2018, 33 (03): 515-525.

[13] Liu Aijun, Wang Baolin, Chen Ximei, et al. Research on the Dynamic Spatiotemporal Characteristics of Grassland Degradation Based on Markov Model [J]. Acta Prataculturae Sinica, 2012, 21 (05): 229-236.