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Response and Vulnerability Analysis of Carbon Storage to Land Use Change in Henan Province

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Abstract: Located in the Central Plains Urban Agglomeration, which is one of the most important grain silos in China, the expansion of construction land is closely related to the economic development and arable land protection in the region, which has led to the problems of “man-land conflict” and “conflict between construction land and arable land” and other issues that have attracted a lot of attention. The Central Plains Urban Agglomeration (CPU) is taken as the study area, and the simulation analysis of urban expansion in CPU is carried out by using land use data and Markov-PLUS model based on the analysis of the current situation. During the study period, the growth of urban construction land area in the Central Plains Urban Agglomeration has experienced the change process of “rapid growth-steady growth-rapid growth-steady growth”. The main land types are mainly arable land, followed by construction land and forest land, with the remaining land types accounting for only about 4% of the total area of the study area; among the four expansion simulation scenarios, in the arable land protection scenario, the downward trend of the arable land area is effectively reduced, with a decrease of 2,675.4 km^2 in comparison with the natural development scenario, but this leads to the encroachment of cultivated land into the eco-land, which results in a certain degree of ecological pressure; in the eco-protection scenario, the eco-land is protected, and the ecological land is protected, and the ecological land is protected. Under the ecological protection scenario, the ecological land has been protected to a certain extent, and the grassland and forest land have increased by 8118.4km^2 and 2071.1km^2 respectively compared with the natural development scenario, while the area of cultivated land has decreased greatly; under the economic development scenario, the area of construction land has increased greatly, and the area of cultivated land has increased by 5003km^2 compared with the natural development scenario, and the area of ecological land has also decreased greatly. In the economic development scenario, the construction land area reaches a large increase, with an increase of 5003km^2 compared with the natural development scenario, a large decrease in cultivated land area, and a decrease in ecological land area. The simulation of construction land expansion in 2035 in the Central Plains Urban Agglomeration under different scenarios shows that the area of arable land will gradually decrease, and the urban construction land should be reasonably and effectively expanded, otherwise it will pose a potential threat to the future security of food production.

Keywords: Urban sprawl; Markov-Plus model; Spatio-temporal evolution simulation; Central Plains Urban Agglomeration.

1. Introduction

Urban agglomerations play an important role in the process of urbanization [1][2]. However, the blind expansion of urban construction land will lead to the continuous shrinkage of arable land, and the contradiction between the supply and demand of urban construction land will be aggravated, which will lead to a lot of ecological problems [3][4]. In this context, rational and effective urban land expansion has become an important issue for China's development[5]. Therefore, modeling and predicting urban expansion and exploring the spatial and temporal evolution of the expansion process can provide scientific and effective references for future urban development planning and the coordinated development between urban construction land and arable land [6].

The simulation of dynamic changes between urban construction land and other land types as a complex system has been a key topic in current geographic research[7]. Currently, the commonly used models about urban expansion can be roughly classified into four kinds: stochastic model, empirical statistical model, optimization model, and dynamic simulation model[8]. Among them, cellular automata (CA), as one of the dynamic simulation models, which has the characteristics of simultaneous discretization of space, state, etc., and considers spatial interactions and temporal causation as local features, has been widely used in urban sprawl simulation research[9]. In 1970, academician Tobler[10] firstly introduced the cellular automata model into urban sprawl simulation research. introduced into urban sprawl simulation studies. However, a single CA model in the complex urban expansion simulation is not able to effectively consider the actual system and planning in the process of urban expansion and cannot reasonably explain the mechanism of urban expansion and other problems [11]. With the advancement of technology and innovation of methodology, researchers have gradually coupled the CA model with other models and applied it to the simulation and study of urban expansion. For example, Liu et al[12] coupled the landscape expansion index with the CA model to simulate and analyze the expansion of urban agglomeration in the Pearl River Delta. Wang Kewen et al[13] coupled Markov model with CA model to simulate and analyze the urban sprawl of the western new city of Chongqing. However. Many current coupled models still have problems such as difficulty in revealing the potential drivers of land use change and capturing the spatial and temporal evolution of urban expansion patches in urban expansion simulation studies. In contrast, the patch-generating Land Use Simulation (PLUS) model proposed by Liang Xun et al[14] adopts a LEAS analysis strategy combined with a CA model based on multi-class stochastic seeds, which makes the model better able to explore the land use changes in simulating urban expansion and better explore the potential drivers of land use changes in the simulation process. In the simulation of urban expansion, the model is able to better explore the causes of land use changes and better simulate the land use patch changes in the simulation process, which fills the simulation needs of land use changes caused by planning policies in urban development, and the simulation results can more scientifically and effectively support the urban development planning[15]. From the research area, the simulation study of urban agglomeration expansion is one of the key topics in urbanization research, and most of the current scholars' studies on the expansion of urban agglomerations are focused on economically developed cities, such as Beijing-Tianjin-Hebei[16], the Yangtze River Delta [17], and the Pearl River Delta[18], and other urban agglomerations. Few studies have conducted systematic analysis and simulation prediction for the Central Plains Urban Agglomeration. The Central Plains urban agglomeration is located in the Central Plains region, which is one of the major grain-producing areas in China, and its arable land covers more than two-thirds of the total area of the study area. However, along with the rapid urbanization of the Central Plains Urban Agglomeration, the land for construction has been encroaching on the arable land, resulting in the continuous decline of the arable land area. Therefore, under this trend, how to accurately simulate and analyze the coordinated development between the expansion of construction land and the protection of arable land is now an important issue in realizing the high-quality development of the Central Plains Urban Agglomeration and the protection of arable land.

This paper takes the Central Plains Urban Agglomeration as the study area, analyzes the spatial and temporal distribution pattern of urban construction land in the Central Plains Urban Agglomeration in 2035 based on the land use data, land use change driving factors, and the coupled Markov model and PLUS model, which are comprehensively included in the macro land use demand forecast, and set up four scenarios, namely, the natural development, arable land protection, ecological protection, and economic development. It explores the changing rules and main trends of urban construction land in the Central Plains Urban Agglomeration, provides a scientific theoretical basis and practice for regional land use planning, as well as a valuable reference for the high-quality development of the Central Plains Urban Agglomeration and the protection of arable land.

Table 1. Three Scheme comparing

Number	Scheme 1	Scheme 2	Scheme 3
1	456	456	123
2	789	213	644
3	213	654	649

2. Materials and Methods

2.1. Study Area

The Central Plains Urban Agglomeration (CPU), which contains thirty municipal cities such as Kaifeng, Heze, Xingtai, etc., is a close-knit circle centered on Zhengzhou, with Kaifeng, Anyang, Jiaozuo, and other regional cities as nodes, with geographic coordinates of 31°23′-37°48′N and 110°13′-118°10′E. It includes the four peripheral demonstration zones of a total of 280,000 square kilometers, and it is situated in China's Central Plains, which can play the role of carrying the east to the west and connecting the north and south on the overall map of China, as shown in Fig. 1. It is located in the Central Plains of China, which can play the role of carrying the east to the west and connecting the north and the south in the overall map of China, as shown in Fig. 1. The gross regional product of the Central Plains Urban Agglomeration in 2020 will be 9.26 trillion yuan, accounting for about 7.65% of the national gross domestic product. According to the data, the resident population of the Central Plains Urban Agglomeration in 2020 will be about 153.31 million, and the per capita GDP will be 60,402.3 yuan.

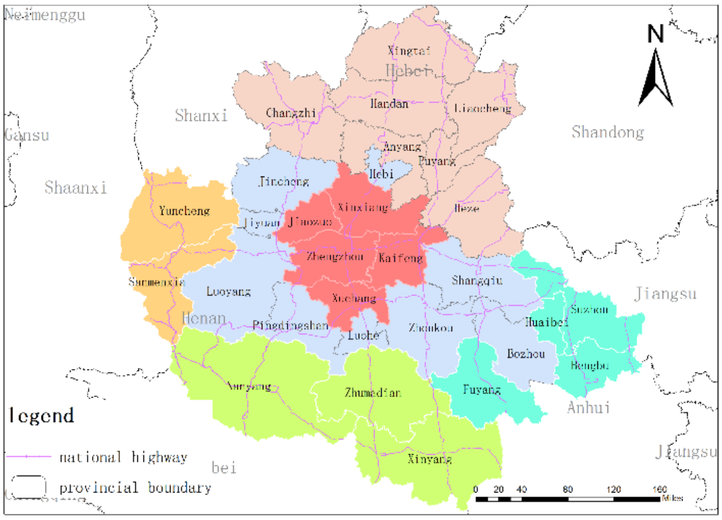

Figure 1. schematic diagram of Central Plains urban agglomeration structure

2.2. Data Collection

The data used in this paper include four categories: land use data, natural conditions data, transportation and road network data, and socio-economic data of the Central Plains Urban Agglomeration. Its details are shown in Table 1. (1) The land use data of the Central Plains Urban Agglomeration is derived from the CLCD dataset of the Earth Resources Data Cloud (http://www.gis5g.com), which categorizes nine categories of cropland, woodland, shrubs, grassland, water bodies, snow and ice, bare soil, construction land, and wetland, with a spatial resolution of 30m×30m.(2) The natural condition data includes DEM data, slope data, etc. The DEM data are from the geospatial data cloud (https://www.gscloud.cn), and the slope data are calculated from the DEM data by the slope module in ArcGIS. (3) Location condition data include road data, water data, etc. The data are from OpenStreetMap. The data were obtained from OpenStreetMap (https://www.openstreetmap.org) (4) Socio-economic data include GDP data, population data, POI data, and night lighting data. The GDP data and population data come from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn). The nighttime lighting data comes from the National Geophysical Data Center of the U.S. The POI data, including municipal government locations, station locations, etc., comes from web crawlers.

Table 1. data source information table

Form	Data	resolution /m
Land use data	1993-2021	30
natural conditions	DEM	30
	Slope	30
transportation network	Class Ⅰ road	vector data
	Class Ⅱ road	
	Class Ⅲ road	
	Class IV road	
	Freeway	
	Provincial road	
	Railroads	
	Water	
social economy	Population density	1000
	GDP	1000
	Night Lights	100
	POI	vector data

2.3. Research Methods

2.3.1. Intensity and rate of urban expansion

In order to quantify the scale of urban expansion, this paper uses Wu et al[19] to derive three indicators for application, including urban construction land expansion rate (expansion rate, ER/%), annual increase (AI/km^2/year), and urban construction land expansion intensity (expansion intensity, EI /%). Among them, the urban construction land expansion rate and annual increase rate directly use the change of urban construction land area to reflect the expansion scale of urban construction land, while the expansion intensity of urban construction land reflects the degree of urban construction land expansion area relative to the overall area of land use. The specific formulas for their calculation are as follows:

$$\text{ER}=\frac{A_j-A_i}{(j-i)\times A_i}\times 100 \tag{1}$$

$$\text{AI}=\frac{A_j-A_i}{j-i} \tag{2}$$

$$\text{EI}=\frac{A_j-A_i}{(j-i)\times S_i}\times 100 \tag{3}$$

where i, j denote the study year, A_i, A_j denote the area of urban built-up land in study year i, j, and S_i denotes the total land use area in year i.

2.3.2. Markov and PLUS models

In this paper, the Markov-PLUS model is used to simulate the spatial and temporal evolution of urban land, which couples the powerful predictive ability of the Markov model with the powerful spatial simulation ability of the PLUS model. The model is able to reveal the influence of each driving factor on the expansion of urban construction land, and the simulation of the patch-level changes of construction land is more accurate, and the simulation results are also closely linked with the future regional development pattern under the current modern social and economic development trend, which can provide an effective scientific basis for optimizing the future territorial spatial development planning of the study area. In this paper, the Markov-PLUS model is used to simulate the urban expansion of the Central Plains Urban Agglomeration in 2035.

(1) Markov model: Markov model is a traditional modeling method applied to land use change, based on Markov process, through the initial transfer probability between different things, to further determine the trend of change between things. Markov analysis model is to simulate the land use state with the help of the current land use state through the transfer probability matrix P_{ij} between the land use data in different periods, in which the initial probability transfer matrix is as follows.

$$\text{Pij}=\begin{bmatrix} p_{11} & \cdots & p_{1n} \\ \vdots & \ddots & \vdots \\ p_{n1} & \cdots & p_{nn} \end{bmatrix} \tag{4}$$

Based on this probability, the land use status prediction formula for the Markov chain model is as follows:

$$S_{t+1} = P_{ij} * S_t \tag{5}$$

Where: St, S_{t+1} denote the state vector of the land use system at time t, t+1 respectively, i.e. the area of each land use type; P_{ij} denotes the transfer probability matrix.

(2) PLUS model: PLUS model (Patch-generating Land Use Simulation, PLUS) is a rule mining framework based on Land Expansion Analysis Strategy (LEAS) and a CA model based on Multiple Random Seeds (CARS). on Multiple Random Seeds, CARS) CA model.

Land Expansion Analysis Strategy (LEAS). In order to realize the simulation of urban land expansion, the first task is to excavate the driving factors and their weights that may image the urban land changes, and there are two common methods used in the CA model for this kind of excavation, i.e., the TAS method (Transition Analysis Strategy) and the PAS method (Pattern Analysis Strategy). The LEAS module, on the other hand, combines the advantages of TAS and PAS, analyzing only the image elements that have undergone transformation, avoiding the data from being too complex while analyzing the driving factors of the results of the two periods. After obtaining the situation of shifted site class image elements, the decision tree-based bagging algorithm (RFC) is used to analyze the correlation between the expansion situation and the driving factors. The RFC algorithm obtains the growth probability $P_{i,k}^{d}(x)$ of outputting the result of the site type at spatial image i for the k class as the following formula:

$$P_{i,k}^{d}(\mathrm{x})=\frac{\sum_{n=1}^{M} I(h_n(x)=d)}{M} \quad (5)$$

Where : x is a vector of multiple drivers; d takes the value of 1 or 0, when the value is 1 it means that there are other site types that change to k-type sites, and 0 means other forms of transformation; $hn(x)$ is the predicted site type of the nth decision tree of the vector x; $I(*)$ is the indicator function of the set of decision trees; M is the total number of decision trees.

$$OP_{i,k}^{d-1,t}=P_{i,k}^{d-1}*\Omega_{i,k}^{t}*D_{k}^{t} \quad (5)$$

where $P_{i,k}^{d-1}$ denotes the growth probability of land use type k in unit i. D_k^t is the adaptive inertia coefficient, which denotes the influence of future land use demand on land use type k, and the factor determining its value is the difference between the number of image elements of land use type k at this point in time when the number of iterations is t and the set target gap, and $\Omega_{i,k}^{t}$ denotes the influence of image element i by the neighboring image elements, specifically the proportion of site type k in the neighboring image elements.

2.3.3. Scenario setting

In order to explore the possible patterns of future development of the Central Plains Urban Agglomeration, this paper constructs four scenarios of natural develop-ment, arable land protection, ecological protection, and economic development in conjunction with the development plan of the Central Plains Urban Agglomeration to simulate and predict the development of urban construction land in the Central Plains Urban Agglomeration in 2035. Since the Markov-PLUS model requires three pre-settings for land use simulation and prediction, including transfer cost matrix set-ting, domain weight parameter setting, and area required for prediction setting. Among them, the transfer cost matrix will limit whether a certain land use type is converted to another land use type, and the domain weights take values ranging from "0 to 1", reflecting the expansion intensity of various land use types, and the larger the value, the stronger the expansion intensity. The area required for the prediction is then calculated by the Markov model through the probability of land use conversion from 2014 to 2021. Therefore, on this basis, four scenarios are set up to meet the forecasting requirements, and the detailed settings are shown in Tables 2 and 3.

Table 2. Weight parameter table of land type domain

Scenario	Cropland	Forest	Shrubland	Grassland	Water	Construction
ND	0.6	0.5	0.5	0.6	0.3	0.9
CP	0.9	0.4	0.3	0.3	0.3	0.4
EP	0.5	0.9	0.8	0.9	0.5	0.4
ED	0.1	0.2	0.2	0.3	0.4	1

Table 3. Transfer matrix of land use types in four situations

Land use	ND						CP						EP						ED					
	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
A	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1	0	1
B	1	1	1	1	1	1	1	1	0	1	0	1	0	1	0	0	0	0	0	1	1	0	1	1
C	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	0	0	0	0	1	1	1	0	1
D	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	0	0	1	0	0	1	0	1
E	1	1	0	1	1	1	0	0	0	1	1	0	0	0	0	1	1	1	1	0	0	1	1	1
F	1	1	0	1	1	1	1	0	0	1	0	1	0	1	1	1	1	1	0	0	0	0	0	1

Note: A: Cropland; B: Forest; C: Shrubland; D: Grassland; E: Waters; F: Construction land; 1: Conversion allowed; 0: Conversion not allowed

Natural development scenario (ND): The natural development scenario is based on the existing urban development trend without any adjustments or parameter changes, and is the basis for modeling and forecasting changes in the other three scenarios;

Cultivated land protection scenario (CP): Since arable land is the main land use type in the Central Plains Urban Agglomeration and urban construction land is mainly derived from arable land, in this scenario, the transfer cost matrix restricts the conversion of arable land to land use types other than construction land; the domain weight increases the domain weight of arable land and decreases that of urban construction land; and the transfer probability reduces the probability of arable land transfer to other land use, and the transfer probability decreases.

Ecological protection scenario (EP): For the transfer cost matrix, limit the conversion of forest land, shrubs, and grassland to construction land; for the domain weights, raise the domain weights of forest land, shrubs, and grassland, and lower the domain weights of cropland and construction land.

Economic Development Scenario (ED): For the transfer cost matrix, conversion of other land types to built-up land will no longer be restricted; for the domain weights, the domain weights for built-up land will be raised and those for the remaining land types will be lowered; and for the transfer probabilities, the transfer probabilities for cropland to built-up land will be raised.

3. Results

3.1. Characteristics of the spatial and temporal evolution of urban land expansion in the Central Plains Urban Agglomeration

Based on the land use data of the Central Plains Urban Agglomeration from 1993 to 2021, ArcGIS spatial analysis tool was used to overlay the land use data of the Central Plains Urban Agglomeration for the five periods of 1993, 2000, 2007, 2014, and 2021, to obtain the spatial pattern of land use and the spatial-temporal evolution of land use data of the Central Plains Urban Agglomeration from 1993 to 2021, and based on this, a land use transfer matrix was constructed to analyze the current situation of urban construction land expansion from

1993 to 2021. The land use transfer matrix is constructed to analyze the current situation of urban construction land expansion in the Central Plains Urban Agglomeration from 1993 to 2021.

3.1.1. S Land Use Patterns in the Central Plains Urban Agglomeration

The land use structure of the Central Plains Urban Agglomeration from 1993 to 2021 is shown in Table 4, and the land use types are always dominated by cropland, accounting for more than 65% of the total land types, followed by forest land and urban construction land, with an average area share of 14.4% and 11.2%, respectively, then grassland, with an average area share of 3.6%, and finally water and shrubs, with an average area share of only 0.9% and 0.2%, respectively. The area transformation of land use types from 1993 to 2021 is shown in the transfer matrix in Fig. 2 and Tables 5, during this period, the major changes in area were in cropland and urban construction land, of which urban construction land increased from 8.5% of the total area of the study area in 1993 to 14.8% of the total area of the study area in 2021, increasing from 24,308.7km^2 to 42,481.5km^2. The urban construction land increased from 8.5% of the total area of the study area in 1993 to 14.8% in 2021, from 24308.7km^2 to 42481.5km^2 , an increase of about 18172.9 km^2 , while the cultivated land gradually decreased from 72.7% of the total area of the study area in 1993 to 65.7% of the total area of the study area in 2021, a total decrease of 7% from 208135.2km^2 to 188122.8km^2 , a decrease of about 20012.4 km^2 , which is basically equal to the increase of the area of the construction land. The total decrease is about 20012.4km^2, which is almost the same as the increase of construction land area. This is followed by changes in grassland and woodland, which decrease by 1.2% and increase by 1.8%, respectively, between 1993 and 2021. Finally, due to the relatively small proportion of water and shrubs in the study area, the fluctuation in area is not significant in relation to the total area of the study area, but in terms of change, water increased by 802.8 km2 and shrubs decreased by 403.6 km^2 during the period, which is also a considerable amount of change.

Table 4. Statistical Table of Land use status of Central Plains Urban agglomeration from 1993 to 2021

Land use type		Construction	Water	Grassland	Shrubland	Forest	Cropland	Total
1993	Area/km^2	24308.7	2497.7	11558.0	574.1	39265.5	208135.2	286339.1
	Cover ratio/%	8.5	0.9	4.0	0.2	13.7	72.7	100
2000	Area /km^2	29441.5	2437.1	12265.9	610.2	39385.8	202198.5	286339.1
	Cover ratio /%	10.3	0.9	4.3	0.2	13.8	70.6	100
2007	Area /km^2	33042.3	3032.9	10356.1	583.6	41505.8	197818.3	286339.1
	Cover ratio /%	11.5	1.1	3.6	0.2	14.5	69.1	100
2014	Area /km^2	38600.3	3033.1	10268.7	358.9	42773.6	191304.5	286339.1
	Cover ratio /%	13.5	1.1	3.6	0.1	14.9	66.8	100
2021	Area /km^2	42481.5	3300.5	7933.2	170.4	44330.7	188122.8	286339.1
	Cover ratio /%	14.8	1.2	2.8	0.1	15.5	65.7	100

Table 5. changes of land use area from 1993 to 2021 (unit: km^2)

Land use type	Construction	Water	Grassland	Shrubland	Forest	Cropland
1993-2000	5132.8	-60.6	707.92	36.18	120.32	-5936.64
2000-2007	3600.9	595.8	-1909.87	-26.59	2120.04	-4380.20
2007-2014	5557.9	0.2	-87.39	-224.76	1267.80	-6513.83
2014-2021	3881.3	267.4	-2335.51	-188.47	1557.05	-3181.75

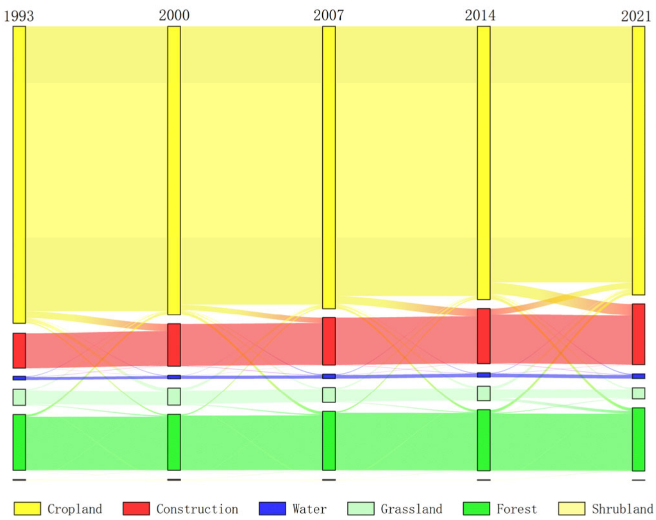

Figure 2. Land use transfer matrix map of Central Plains urban agglomeration 1993-2021

3.1.2. Spatial and Temporal Evolution Patterns of Urban Construction Land in the Central Plains Urban Agglomeration

In this paper, the center of gravity migration model and the method of standard deviation ellipse are used to characterize the spatial distribution of construction land in the Central Plains urban agglomeration, as shown in Figure 3. The center of gravity of construction land in the Central Plains Urban Agglomeration moves slowly during 2000-2007 and 2014-2021, while it moves rapidly during 1993-2000 and 2007-2014. Spatially, the center of gravity of construction land in the Central Plains Urban Agglomeration always moves towards Zhengzhou, experiencing the process of "southwest-northwest-northwest-southwest". The flatness of the standard deviation ellipse of the construction land of the Central Plains Urban Agglomeration is always between 90° and 180°, i.e., the direction is always in the direction of "northwest-southeast", but deflected to the east-west direction, and during this period, it moves from 144° in 1993 to 146° in 2021, which is just a two-degree movement. It shows that the Urban Agglomeration of the Central Plains has formed a "meter" development pattern with Zhengzhou City as the core and the city belt of Beijing-Guangzhou Railway and the city belt of Longhai Railway as the backbone of the development, which promotes the rapid development of the Urban Agglomeration of the Central Plains.

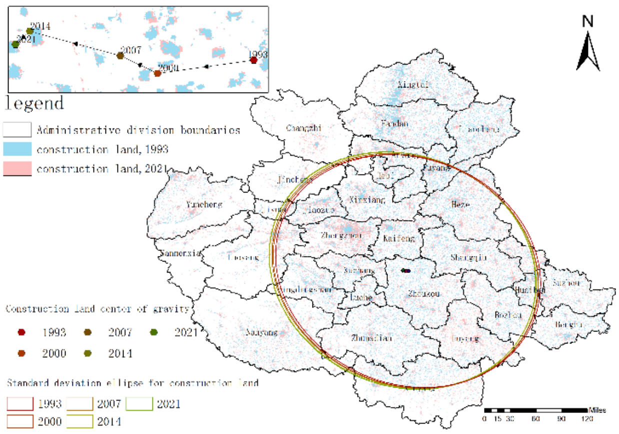

Figure 3. Spatio-temporal variation of standard deviation ellipse and center of gravity of construction land in Central Plains urban agglomeration

In terms of the scale of urban expansion, this paper selects the expansion rate (ER), annual growth (AI) and expansion intensity (EI) as three indicators for analysis. The expansion area, expansion rate, annual growth rate and expansion intensity of the Central Plains Urban Agglomeration for the period of 1993-2021 are shown in Table 6.From the analysis of the expansion area, the Central Plains Urban Agglomeration in the time period of 2007-2014 reached the highest value in the study period, with the expansion area, annual growth rate and expansion intensity reached the highest value in the study period, reaching 5557.94km^2, 793.99km^2/year and 0.28% respectively, indicating that the urbanization level of the Central Plains Urban Agglomeration reached the highest in this time period, and the expansion scale of urban construction land hit the maximum. And the expansion rate in 1993-2000 reached the highest value in the study period, indicating that at the beginning of the study period, due to the relatively small area of urban construction land, the expansion area was only 425.14km^2 different from the maximum value of the expansion area in the study period, and it also reached 5,132.80km^2, and the level of urbanization was still very high. Therefore, during the period of 1993-2021, the expansion of urban construction land in Central Plains cities has experienced the change process of "rapid growth-steady growth-rapid growth-steady growth".

Table 6. Expansion of construction land in Central Plains urban agglomeration from 1993 to 2021

research period	expansion area /km^2	ER/%	AI/km^2/year	EI/%
1993-2000	5132.80	3.02	733.26	0.26
2000-2007	3600.86	1.75	514.41	0.18
2007-2014	5557.94	2.40	793.99	0.28
2014-2021	3881.26	1.44	554.47	0.19

3.2. Multi-scenario Simulation and Forecasting of Urban Construction Land Expansion in the Central Plains Based on the PLUS Model

3.2.1. PLUS model simulation accuracy validation

In order to verify the practicality of Markov-PLUS model in the Central Plains Urban Agglomeration region, this paper selects the land use data of 2007 and 2014, and then combines the collected data of 14 driving factors to calculate the development prob-ability atlas of various land use types by using the LEAS module of the PLUS model, and then uses the atlas combined with the CAS module of the PLUS model to carry out the Land use simulation, after the completion of the simulation using the Kappa coefficient, the overall accuracy and the FOM value to verify the accuracy of the model simulation results, the study shows that the Kappa coefficient value is greater than 75%, it is considered that the model simulation results are more accurate, and it can effectively carry out the simulation and prediction of the future land use pattern of the region.

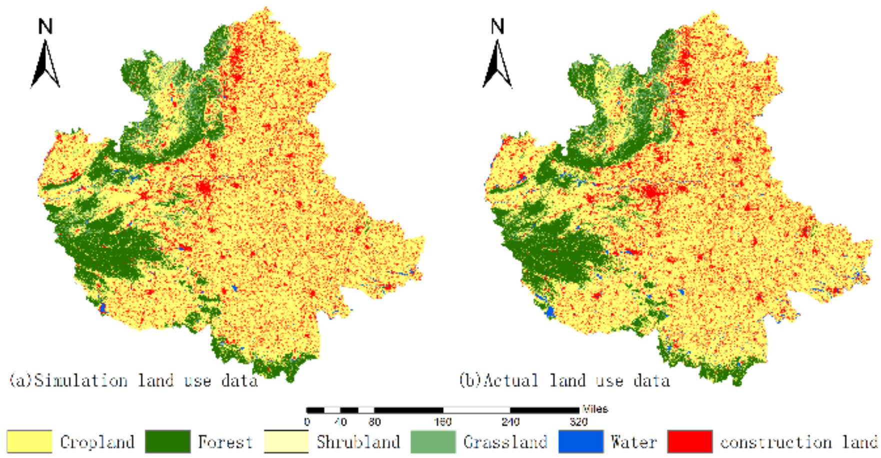

Figure 4. Comparative map of simulation and actual land use space of Central Plains urban agglomeration in 2021

Taking 2014 as the base year period data, the PLUS model is used to simulate the land use simulation map in 2021 based on the development probability atlas of various land use types trained in 2007-2014, and then carry out the accuracy verification with the real land use map in 2021, and the results are shown in Figure 4. The value of Kappa coefficient is obtained as 0.811, the overall accuracy is 0.901, and the value of FOM is 0.029. It indicates that the PLUS model has a better simulation effect in the Central Plains Urban Agglomeration region, and the simulation can be used for the simulation and prediction of land use of the Central Plains Urban Agglomeration in 2035.

3.2.2. Multi-scenario simulation of future changes in urban built-up area

In the multi-scenario simulation study of future urban construction land change, based on the land use expansion from 2014 to 2021 and the data of 14 driving factors, the development suitability atlas of each land type is calculated with the help of the LEAS module of the PLUS model, and then based on the calculated development suitability atlas, with the help of the CAS module of the PLUS model, the land use map of 2021 is used as the initial data to simulate the land use situation under four different scenarios in the Central Plains urban cluster in 2035, and the spatial distribution of land use simulation is shown in Figure 5. Then, based on the calculated development suitability atlas, with the help of CAS module of PLUS model, the land use map in 2021 is used as the initial data to simulate the land use in four different scenarios of the Central Plains Urban Agglomeration in 2035, and the spatial distribution of the land use simulation is shown in Fig. 6, and the area of the simulated land use types is shown in Table 7. By analyzing the land use situation under the four development scenarios, it can be seen that the urban construction land under the natural development scenario is still showing a steady expansion trend, increasing to 42501.1km^2 by 2035, the area of arable land and the area of grassland are still decreasing, falling by 5474km^2 and 2355.9km^2, respectively, and the area of woodland is showing a small increase in the trend of the area change is not obvious. Under the development scenario of arable land protection, the area of arable land still shows a decreasing trend, only the decreasing trend of arable land area is slowed down relative to the natural development scenario, and the construction land still shows an expanding trend, only the intensity of the expansion has a small decrease, while the forest land, shrubs and grasslands have changed relative to the natural development scenario, the area of forest land has changed from a small increase to a small decrease, and the area of shrubs and grasslands have further increased in decrease, respectively, down by 5,474km^2 and 2,355.9km^2 . Under the ecological protection scenario, the area of cultivated land and the area of construction land still show a downward and upward trend, while the area of forest land has been greatly improved, and the downward trend of the area of grassland and the area of shrubs has been alleviated to a certain extent. Under the economic development scenario, compared with 2021, the growth of construction land area is greatly improved, increasing by about 11067.4km^2, while the cultivated land area and grassland area still show a decreasing trend, and the forest land area shows a small increase trend.

From a comprehensive view of the four scenarios of land use changes in the Central Plains Urban Agglomeration in 2035, since the Central Plains Urban Agglomeration is located in the central plains, and the soil and climate are suitable for growing food, the area of arable land is much larger than that of the other types of land, and most of the land used for construction is bordered by arable land, so the contradiction between construction land and arable land becomes more and more prominent along with the development and expansion of the Central Plains Urban Agglomeration. As far as the protection of arable land is concerned, although the decreasing trend of arable land area has been curbed, the development of construction land has gradually encroached on grassland and forest land, which has caused great pressure on the ecology. In the context of ecological protection and economic development, the former needs to ensure that the area of ecological land can not be reduced too much, while the latter needs to ensure economic development, both of which will lead to a significant reduction in the area of arable land, resulting in a decrease in food production.

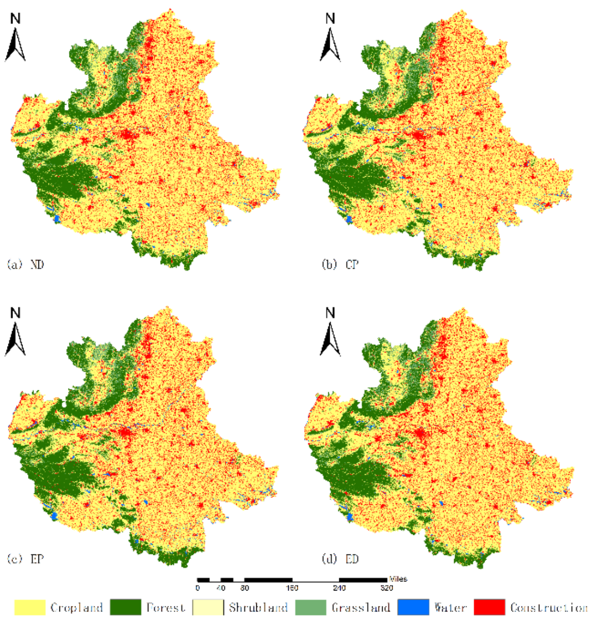

Figure5. Land use under four development scenarios of Central Plains urban agglomeration in 2035

Table 7. Land use in four development scenarios of Central Plains Urban agglomeration in 2035 (unit: km^2)

Scenarios	Cropland	Forest	Shrubland	Grassland	Water	Construction
2021 Land use status	188112.2	44325.1	170.4	7932.4	3297.9	42501.1
2035 ND	182636.7	45728.9	104.3	5576.5	3727.2	48565.5
2035 CP	185312.1	44267.1	99.1	5321.2	3522.1	47817.3
2035 EP	173128.0	53847.3	119.8	7647.6	3713.3	47882.9
2035 ED	177902.0	45505.7	104.1	5522.4	3736.4	53568.5

4. Conclusion

This paper takes the Central Plains Urban Agglomeration as the study area, and based on the land use coverage data from 1993-2021, the Markov-PLUS model is used to analyze the spatial and temporal evolution pattern of the expansion of the study area, and simulate and predict the evolution of the expansion of the multi-scenarios, and the conclusions are as follows: ① The main land use types in the Central Plains Urban Agglomeration are mainly arable land, with the construction land and forest land secondly, and the area of the rest of the land types only accounts for about 4% of the total area of the study area. The area of the remaining land types only accounts for about 4% of the total area of the study area. During the period of 1993-2021, the rapid development of the cities in the Central Plains Urban Agglomeration has led to a continuous increase in the area of construction land, resulting in a continuous decrease in arable land. The growth of urban construction land area has experienced the change process of "rapid growth-steady growth-rapid growth-steady growth". The Markov-PLUS model is used to simulate the land use pattern of the Central Plains Urban Agglomeration in 2021, and then the accuracy is verified by comparing it with the actual land use map in 2021, and the Kappa coefficient value of the model is 0.811, the overall accuracy is 0.901, and the value of FOM is 0.029, which is a higher accuracy of the simulation results, indicating that the model can effectively simulate the future land use pattern of the study area. simulation prediction of future land use pattern in the study area. The simulation results of the four expansion scenarios of the Central Plains Urban Agglomeration in 2035 show that, under the cropland protection scenario, the downward trend of cropland area is effectively reduced, and compared with the natural development scenario, it is reduced by 2,675.4 km^2, and the expansion of construction land is also suppressed to a certain extent, but it leads to the encroachment of cropland into the ecological land, which results in a certain amount of ecological pressure; under the ecological protection scenario, the ecological land is protected, and grassland and forest land are compared with the natural development scenario. Under the ecological protection scenario, the eco-logical land has been protected to a certain extent, and the grassland and forest land have increased by 8118.4km^2 and 2071.1km^2 respectively compared with the natural development scenario, and the expansion of construction land has been suppressed to a certain extent, but the area of arable land has decreased significantly; under the economic development scenario, the area of construction land reaches a substantial increase, and the area of ecological area and the area of arable land have decreased, while the area of construction land has increased by 5003km2 more than that of the natural development scenario.

The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph). All manuscripts must be in English, also the table Conclusion

The manuscript should include a conclusion. In this section, summarize what was described in your paper. Future directions may also be included in this section. Authors are strongly encouraged not to reference multiple figures or tables in the conclusion; these should be referenced in the body of the paper.

References

[1] Zhu Z ,He Q .Spatio-temporal evaluation of the urban agglomeration expansion in the middle reaches of the Yangtze River and its impact on ecological lands[J].Science of the Total Environment,2021,790148150-148150.

[2] Fang C L, Zhou C H, Gu C L, et al. Theoretical framework and technical path for analyzing the interactive coupling effect of urbanization and ecological environment in mega-urban agglomeration[J]. Acta Geographica Sinica,2016,71(04):531-550.

[3] Wang L H, Zhang J M. Analysis on the driving Force of Spatial expansion of Oasis cities and towns based on Geographic detector-- A case study of Shihezi City, Xinjiang[J]. Regional Research and Development,2019,38(04):68-74.

[4] Guangzhao C ,Xia L ,Xiaoping L , et al.Global projections of future urban land expansion under shared socioeconomic pathways.[J].Nature communications,2020,11(1):537.

[5] Cui X ,Fang C ,Liu H , et al.Assessing sustainability of urbanization by a coordinated development index for an Urbanization-Resources-Environment complex system: A case study of Jing-Jin-Ji region, China[J].Ecological Indicators,20 19,96383-391.

[6] Xuanchi C ,Zongmin W ,Haibo Y , et al.Enhanced urban growth modelling: Incorporating regional development heterogeneity and noise reduction in a cellular automata model a case study of Zhengzhou, China[J].Sustainable Cities and Society,2 023,99

[7] Wang X, Ma B W, Li D, et al. Multi-scenario Simulation and Prediction of Ecological Space in Hubei Province based on FLUS Model[J]. Journal of Natural Resources,2020,35(01):23 0-242.

[8] Tian Y, Xioang C S. Simulation of Urban expansion considering the aggregation and exclusion of Construction Land: a case study of Yiwu City[J]. Geographical Research, 2024,43(04):861-873.

[9] Zhao L , Yang J, Li C, et al. Research Progress of Geographic Cellular Automata Model[J]. Scientia Geographica Sinica

[10] Tobler R W .A Computer Movie Simulating Urban Growth in the Detroit Region[J].Economic Geography,1970,46234-240.

[11] Fragkias M ,Seto C K .Modeling Urban Growth in Data-Sparse Environments: A New Approach[J].Environment and Planning B: Planning and Design,2007,34(5):858-883.

[12] Liu ,Ma ,Li , et al.Simulating urban growth by integrating landscape expansion index (LEI) and cellular automata[J]. International Journal of Geographical Information Science,201 4,28(1):148-163.

[13] Wang K W, Qin J , Ma H T. Simulation of Spatio-temporal Evolution and Ecological response of Urban expansion of New towns in Western Chongqing based on CA-Markov Model[J]. Journal of University of Chinese Academy of Sciences, 2023,40(04):496-505.

[14] Xun L ,Qingfeng G ,C. K C , et al.Understanding the drivers of sustainable land expansion using a patch-generating land use simulation (PLUS) model: A case study in Wuhan, China[J].Computers, Environment and Urban Systems,2021,8 5101569-.

[15] Lan J, Qu L Q. Multi-scenario Simulation of Land use and Evaluation of carbon reserves in the Pearl River Basin in the next 10 years[J/OL].Journal of Soil and Water Conservation, 1-10[2024-05-15].https://doi.org/10.13870/j.cnki.stbcxb.2024. 03.026.

[16] Wu A B, Chen F G, Zhao Y X, et al. Multi-scenario Simulation of Construction Land expansion in Beijing-Tianjin-Hebei Urban agglomeration and its impact on ecosystem carbon Storage[J/OL]. Environmental Science, 1-20[2024-04-15].https://doi.org/10.13227/j.hjkx.202305221.

[17] Li Tianqi. Research on spatio-temporal characteristics and influencing factors of urban expansion in Yangtze River Delta Urban Agglomeration [D]. Anhui University of Finance and Economics,2022.DOI:10.26916/d.cnki.gahcc.2022.000649.

[18] Hu P P, Li F, Hu D, et al. Spatial and temporal characteristics of urban expansion in Pearl River Delta urban agglomeration from 1980 to 2015[J]. Acta Ecologica Sinica, 2021,41(17): 7063-7072.

[19] Wu W ,Zhao S ,Zhu C , et al.A comparative study of urban expansion in Beijing, Tianjin and Shijiazhuang over the past three decades[J].Landscape and Urban Planning,2015,13493-106.