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Spatiotemporal evolution and prediction of habitat quality in Hohhot City of China based on the InVEST and CA-Markov models

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Abstract: With the acceleration of urbanization, changes in the urban ecological environment and landscape pattern have led to a series of prominent ecological environmental problems. In order to better coordinate the balanced relationship between city and ecological environment, we selected land use change data to evaluate the habitat quality in Hohhot City of China, which is of great practical significance for regional urban and economic development. Thus, the integrated valuation of ecosystem services and tradeoffs (InVEST) and Cellular Automata-Markov (CA-Markov) models were used to analyze, predict, and explore the Spatiotemporal evolution path and characteristics of urban land use, and forecast the typical evolution pattern of land use in 2030. The results showed that the land use types in Hohhot City changed significantly from 2000 to 2020, and the biggest change took place in cultivated land, grassland, shrub, and artificial surface. The decrease of cultivated land area and the increase of artificial surface area were the main impact trend of land use change. The average value of habitat quality had been decreasing continuously from 2000 to 2020, and the values of habitat degradation were 0.2605, 0.2494, and 0.2934 in 2000, 2010, and 2020, respectively, showing a decreasing trend. The decrease of habitat quality was caused by the needs of economic development and urban construction, as well as the impact of land occupation. During this evolution, many cultivated land and urban grassland had been converted into construction land. The simulated land use changes in 2030 are basically the same as those during 2000–2020, and the habitat quality will still be declining. The regional changes are influenced by the urban rapid development and industrial layout. These results can provide decision-making reference for regional urban planning and management as well as habitat quality evaluation.

Keywords: land use; urbanization; InVEST; CA-Markov; habitat quality; Hohhot City

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1 Introduction

Urbanization construction leads to the change of land use structure and scale, which affects the regional ecological environment quality level. On the one hand, the construction of urban infrastructure expands the material space of urban development, on the other hand, it certainly has a negative impact on the sustainable development of regional cities and towns. Therefore, evaluating the impact of regional land use change during urbanization on habitat quality is

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conducive to objectively revealing the balance relationship between land use and eco-environmental carrying capacity. The expansion of urbanization has occupied part of cultivated land, forest, and grassland, which has destroyed the original functions of the land, thereby resulting in ecological imbalance and the urban landscape pattern change (Bai et al., 2020; Zhou et al., 2021). According to the coordination relationship between human demand and ecological environment carrying capacity, habitat quality can be affected by human social activities and economic development level, so it can reflect the suitability level of ecological environment. In addition, the habitat quality can be qualitatively and quantitatively evaluated by using models to predict the relationship between urbanization development and ecological environment. The changes of land use types, intensity, and landscape patterns caused by human activities lead to the fragmentation of regional land landscape patterns and the squeeze of ecological development space, which then affect the diversity of changes in regional habitat quality (Laurance et al., 2014; Haddad et al., 2015).

Hohhot City is one of the important central cities in the northern border region of China. Due to the rapid development of urbanization and industrialization in recent years, land use pattern and ecological environment have changed dramatically, which causes the sharp decline in the quality of urban human settlements and habitats. In this case, it is necessary to analyze the temporal and spatial changes of land use structure, predict the future land use structure, and explore the relationship between regional land use change and habitat quality, which has important practical significance to promote the coordinated and sustainable development of cities and regions. Scholars at home and abroad have been using the combination of qualitative and quantitative methods to evaluate habitat quality from different angles and scales for a long time. Hence, the research means and models are relatively perfect. The change of land use type is an important factor causing the evolution of habitat quality, thus giving rise to the emergence of the development of a land use simulation model. For example, the Cellular Automata (CA) model is one of the earliest application models (Li et al., 2020). Other models are derived from the CA model (Wu, 2002), the conversion of land use and its effects at small region extent (CLUE-S) model (Verburg et al., 2002), future land use simulation (FLUS) model (Li et al., 2010), patch-generating land use simulation (PLUS) model (Liang et al., 2021), and distributed land-use change prediction (DLUCP) model (Wang et al., 2021). The Cellular Automata-Markov (CA-Markov) model combines the advantages of CA model and Markov model, which can simulate the spatial change of complex systematic (Matlhodi et al., 2021; Mokarram et al., 2021). At present, the types of land use simulation have expanded from the single type to multiple types. For example, a study conducted by Gao et al. (2021) simulated land use change and ecosystem service value under multiple scenarios. Domestic research on habitat quality has been focusing on habitat quality evaluation (Wu et al., 2015; Liu et al., 2017). The mostly used research methods are evaluation methods, such as the system dynamics method, net primary productivity (NPP) and normalized difference vegetation index (NDVI) habitat index evaluation, and integrated valuation of ecosystem services and tradeoffs (InVEST) model. The InVEST model has been extensively applied to the evaluation of the regional habitat quality and favorable evaluation results have been achieved (Chen et al., 2016; Qi et al., 2021; Yang and Wu, 2021). It has become a hot spot in the studies of habitat quality change to simulate land use change and habitat quality change using multiple land use type change data (Hu, 2020). The CA-Markov model has a mature research basis for predicting the impact of land use change on regional habitat quality, and the prediction simulation accuracy is high. The simulation results have certain reference value for ecological space optimization, layout, and habitat quality assessment in the study area. Based on the above research foundations, evaluating the evolution characteristics of habitat quality and predicting the trend of land use change by simulation methods are of great research significance for urban and regional ecological environment protection and urban sustainable development.

In summary, the InVEST model has laid a good foundation for exploring regional urban habitat quality by evaluating habitat threat sources and sensitive sources. Based on the empirical data of land use change during 2000–2020, we quantitatively and qualitatively evaluated the intensity of land use and habitat quality in this study. Therefore, herein, the InVEST model and CA-Markov model were applied to the evaluation of habitat quality in Hohhot City in 2000, 2010, and 2020. Besides, the land use change of Hohhot City in 2030 was also forecasted. From the perspective of spatial analysis, we proposed measures to reduce the differences and improve the cooperative balance of regional ecology, evaluated the evolution of habitat quality and the leading factors of synergistic impact in Hohhot City, and constructed a dynamic balance model to solve the change of urban ecological environment quality and land use. These evaluation results can provide decision-making reference for regional urban development.

2 Materials and methods

2.1 Study area

Hohhot City (40°51′–41°08′N, 110°46′–112°10′E) is located in the central of Inner Mongolia Autonomous Region, China. The terrain structure is mainly mountainous and features plain terrain as the main geomorphic unit. The terrain gradually slopes from northeast to southwest, the highest elevation is 2280 m, and the lowest is 986 m. The climate type belongs to Mongolian plateau climate with four distinct seasons. The total area of the city was about 17,166.66 km^2, including 8525.64 km^2 of cultivated land, 5993.77 km^2 of grassland, 1040.69 km^2 of forest, 1039.39 km^2 of artificial surface, 437.52 km^2 of shrubland, 73.78 km^2 of water body, 36.75 km^2 of wetland, and bareland of 19.13 km^2 in 2020. The gross domestic product (GDP) was 2.807×10^{10} CNY and the total population was 3.496×10^{7} in Hohhot City in 2020, including urban people of 2.785×10^{7} and rural people of 7.100×10^{5}, with an urbanization rate of 79.7% (Statistics Bureau of Hohhot, 2020).

2.2 Data sources

Herein, the habitat quality module in the InVEST model was used to evaluate habitat quality, and the IDRISI 17.0 software was used to simulate land use evolution data. The land cover change data in 2000, 2010, and 2020 were obtained from the Resource and Environment Science and Data Center (http://www.resdc.cn; accessed on 1 January 2020). All the image data were 30 m×30 m grids through mosaicking, cropping, splicing, and interpretation, and the data accuracy was over 85%. Digital Elevation Model (DEM), highway, railway, municipal road data, and other data were downloaded from the website of the Geographic Data Cloud (https://www.gscloud.cn/sources/). The base data of the map came from the National Platform for Common Geographic Information Services (https://www.tianditu.gov.cn/). The raster data of Hohhot City were obtained by cutting, processing, and splicing, and the threat sources and factors of habitat quality were selected by referring to the research results of the same or similar regions. The annual economic data in 2000, 2010, and 2020 were derived from the Hohhot Statistical Yearbook (Statistics Bureau of Hohhot, 2020).

2.3 Methods

2.3.1 Cellular Automata-Markov (CA-Markov) model

The CA-Markov model integrates the temporal and spatial dynamic changes of the CA model and the land use transfer prediction function of the Markov model. The CA model is a spatiotemporal simulation model of land use based on discontinuity, which is characterized by discrete space, time, and state, and usually involves four factors including unit, adjacent range, state, and transformation rules (Wang et al., 2021). The calculation can be expressed as:

$$s_{(t+1)} = f(s_t, N), \tag{1}$$

where s is the finite discrete state set; N is the domain; t is the time; and f is the state transformation rule.

The Markov model predicts the initial state vector and applies the transition probability decision matrix to simulate the stability of land use change. This model can be used to predict and determine the transition probability (p_{ij}) at time t, thus realizing the transition from one state of the system to another. The calculation expression is as follows:

$$P_{ij} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{bmatrix}, \tag{2}$$

where p_{ij} is the transition probability from land use type i to land use type j during study period; and n is the number of land use types.

Based on such probability, we established the Markov model of land use as follows:

$$s^{(k+1)} = s^{(k)} p_{ij} = s^{(0)} p_{ij}^{(k+1)}, \tag{3}$$

$$0 \le p_{ij} < 1 \text{ and } \sum_{j=1}^{n} p_{ij} = 1 (i, j = 1, 2, \cdots, n), \tag{4}$$

where $s^{(k+1)}$ is the state vector when the predicted land use type equals to k+1; $s^{(k)}$ is the state vector when the predicted land use type equals to k; and $s^{(0)}$ is the prediction result.

2.3.2 Simulation accuracy verification

The accuracy of land use evolution simulation model was verified using the Kappa coefficient (Rahnama et al., 2020; Wang et al., 2021), and the calculation expression is as follows:

$$\text{Kappa coefficient} = \frac{(p_0 - p_e)}{(p_0 - p_e)}, \tag{5}$$

where p_0 is the correct simulated proportion value; and p_e is the simulated predicted proportion under the stochastic conditions.

2.3.3 Habitat quality assessment

Considering a series of data, such as main threat factors and sensitive sources, the habitat quality module of the InVEST model is superior in the case of evaluating the habitat quality, which is an index reflecting the regional biodiversity and suitability. A higher regional habitat quality indicates a higher biodiversity level, and vice versa. The calculation formulas are as follows:

$$Q_{xj} = H_j \left(1 - \frac{D_{xj}^z}{D_{xj}^z + K^z} \right), \tag{6}$$

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{w_r}{\sum_{r=1}^{R} w_r} \right) r_y i_{rxy} \beta_x S_{jr}, \tag{7}$$

where Q_{xj} is the habitat quality of land use type j in grid x; H_j is the suitability of ecological landscape; D_{xj} is the degradation degree of ecological quality; and K is a semi-saturated parameter; z is the default model parameter; R is the threat factor; Y_r is the total number of grids of the threat layer on the land type layer; w_r is the weight of threat factor; r_y is the number of threat factors; i_{rxy} is the threat level of habitat quality; β_x is the level of legal protection; and S_{jr} is the sensitivity degree index of land use type j to threat factors.

The range values of model parameters in this paper refer to previous relevant research results (Tang et al., 2015; Pan et al., 2018). Besides, by consulting experts in relevant fields, we formulated the threat sources and weight of habitat quality in Hohhot City (Table 1), as well as the habitat suitability degree and its sensitivity degree to threat sources (Table 2).

Table 1 Threat sources and weight of habitat quality in Hohhot City

Threat source	Maximum influence distance (km)	Weight	Degradation type
Cultivated land	3	0.7	Linear
Artificial surface	5	1.0	Exponential
Bareland	1	0.4	Linear

Table 2 Habitat suitability degree of land use types and relative sensitivity to the three threat sources

Land use type	Habitat suitability degree	Sensitivity degree		
		Cultivated land	Artificial surface	Bareland
Cultivated land	0.5	0.3	0.5	0.3
Forest	0.8	0.5	0.7	0.4
Grassland	0.6	0.4	0.6	0.3
Shrubland	0.7	0.3	0.5	0.3
Wetland	0.9	0.6	0.8	0.3
Water body	0.9	0.6	0.8	0.6
Artificial surface	0.0	0.0	0.0	0.0
Bareland	0.0	0.0	0.0	0.0

3 Results

3.1 Land use and transfer changes

The land use types in the study area mainly included cultivated land, forest, and grassland, covering 94.51% of the total land area of Hohhot City, of which cultivated land accounted for the most, about 52.49% (Fig. 1). From 2000 to 2020, the regional land use types in Hohhot City had changed significantly (Table 3), with larger change in cultivated land, grassland, shrubland, and artificial surface. Land use types featuring a reduction trend were mainly cultivated land, grassland, wetland, and bareland. The cultivated land area decreased by 484.92 km^2, with a reduction rate of 0.27%; the grassland area decreased by 333.68 km^2 and the reduction rate was 0.26%; the wetland area decreased by 37.48 km^2, with a reduction rate of 2.52%; the bareland area decreased by 6.45 km^2, with a reduction rate of 1.26%; the forest area increased by 153.08 km^2, with an increase rate of 0.86%; the shrubland area increased by 303.33 km^2, with an increase rate of 11.30%; the water body area increased by 11.52 km^2, with an increase rate of 0.92%; and the artificial surface area increased by 394.62 km^2, with an increase rate of 3.06%. The decrease of cultivated land area and the increase of artificial surface area were the main trend of land use change. During 2000–2020, the increase of urban construction land, population growth, and economic construction needs in Hohhot City had led to the decrease of cultivated land. In addition, the areas of forest, water body, and shrubland had increased due to the introduction of returning farmland to forest and grassland in 2010 and the demand for the improvement of the urban living environment and the urban greening rate, such as urban landscape greening construction. The results revealed that the range of land use change in Hohhot City from 2000 to 2020 is large and its types are multiple, which is mainly attributed to urban construction, economic development, population growth, and other factors.

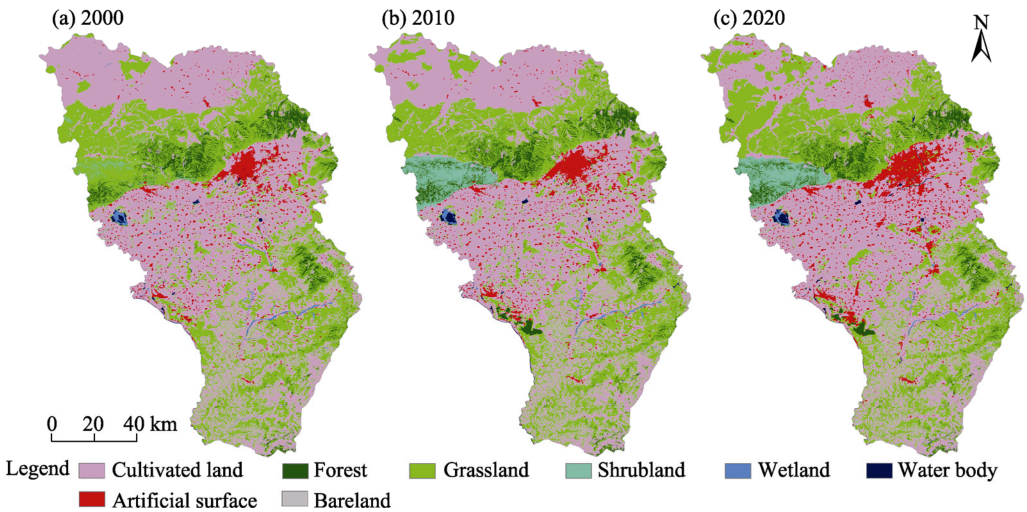

Fig. 1 Spatial distribution of land use types in Hohhot City in 2000 (a), 2010 (b), and 2020 (c)

Table 3 Statistics of land use change rate in Hohhot City from 2000 to 2020

Parameter	Cultivated land	Forest	Grassland	Shrubland	Wetland	Water body	Artificial surface	Bareland
Area in 2000 (km^2)	9010.56	887.62	6327.45	134.19	74.23	62.26	644.78	25.59
Area in 2022 (km^2)	8525.64	1040.69	5993.77	437.52	36.75	73.78	1039.39	19.13
Change in area between 2000 and 2020 (km^2)	–484.92	153.08	–333.68	303.33	–37.48	11.52	394.62	–6.45
Rate of change (%)	–0.27	0.86	–0.26	11.30	–2.52	0.92	3.06	–1.26

The transfer matrix of land use change revealed the land use change in Hohhot City. It can be observed from Table 4 that, from 2000 to 2010, cultivated land was the land use type that was transferred out the most with a net transfer-out of 326.03 km^2, mainly 753.78 km^2 into grassland, and 134.34 km^2 into artificial surface. This situation is mainly attributed to the demand for returning farmland to grassland and urban construction. A total of 324.46 km^2 of shrubland was transferred, of which 30.07 km^2 of shrubland was transferred to grassland and 58.38 km^2 of shrubland was transferred to forest, indicating that the shrubland was destroyed and turned to the grassland, which was also the main source of forest. The net transfer-out of grassland was 231.09 km^2, 486.70 km^2 turning to cultivated land, 370.61 km^2 turning to shrubland, and 388.93 km^2 turning to forest, showing that the conversion of grassland to cultivated land still accounted for a certain proportion.

Table 4 Transfer matrix of land use types in Hohhot City from 2000 to 2010 and from 2010 to 2020

Land use type	Grassland (km^2)	Cultivated land (km^2)	Shrubland (km^2)	Bareland (km^2)	Artificial surface (km^2)	Forest (km^2)	Wetland (km^2)	Water body (km^2)	Transfer-out (km^2)	Net transfer-out (km^2)
2000–2010										
Grassland	5040.54	486.70	370.61	8.00	27.02	388.93	2.49	8.53	1292.29	231.09
Cultivated land	753.78	8067.66	9.27	1.38	134.34	26.06	5.11	7.57	937.51	326.03
Shrubland	30.07	2.45	42.95	0.02	0.11	58.38	0.03	0.17	91.23	–324.46
Bareland	7.72	1.14	0.51	16.10	0.07	0.05	-	0.00	9.49	0.07
Artificial surface	13.18	74.31	1.38	0.01	554.20	0.83	0.15	0.71	90.58	–74.10
Forest	243.85	20.55	33.71	0.02	0.37	588.41	0.55	0.16	299.21	–175.62
Wetland	8.39	14.32	0.04	-	0.47	0.40	41.43	9.19	32.80	21.57
Water body	4.21	12.01	0.18	-	2.29	0.18	2.89	40.50	21.76	–4.58
Transfer-into	1061.21	611.48	415.70	9.41	164.68	474.83	11.23	26.34	-	-
2010–2020										
Grassland	4646.21	1021.36	4.91	11.02	107.22	302.96	2.25	5.83	1455.54	103.96
Cultivated land	989.83	7258.75	6.08	4.17	375.81	21.76	4.95	17.79	1420.39	157.53
Shrubland	5.75	26.31	342.20	0.89	2.50	80.72	0.03	0.25	116.45	21.14
Bareland	15.39	5.44	1.10	2.69	0.80	0.07	0.01	0.01	22.82	6.38
Artificial surface	21.76	147.88	1.66	0.07	545.98	0.65	0.07	0.80	172.89	–320.51
Forest	307.19	35.03	81.45	0.23	4.81	634.01	0.32	0.20	429.23	22.55
Wetland	2.52	16.52	0.01	-	0.88	0.44	27.61	4.67	25.05	15.92
Water body	9.14	10.32	0.09	0.06	1.39	0.10	1.52	44.22	22.62	–6.93
Transfer-into	1351.58	1262.86	95.31	16.44	493.40	406.68	9.13	29.55	-	-

Note: - represents no change.

Regarding the change of land use types from 2010 to 2020, the net transfer-out of cultivated land was 157.53 km^2, the net transfer-out of grassland was 103.96 km^2, and the net transfer-out of artificial surface was 320.51 km^2. In this case, the change of land use types in Hohhot City was mainly attributed to the needs of urban construction. The transfer of artificial surface was obvious. There was 147.88 km^2 of artificial surface converted from cultivated land, which might result from the fact that the problem of disorderly occupation of cultivated land was still prominent, thus resulting in the occupation of cultivated land into artificial surface.

From 2000 to 2020, the transfer trend of land use types in Hohhot City was obvious, mainly characterized by the transfer of artificial surface, cultivated land, and grassland, indicating that the rapid economic growth and increased population during 2000–2020 had led to the expansion of urban land. In addition, people also paid attention to protecting of the ecological environment and promoting the increase of urban grassland and forest areas during 2000–2020.

3.2 Habitat degradation degree

The habitat degradation degree reflects the probability of the reduction degree of habitat degradation. The value range of habitat degradation degree (0.0000–1.0000) shows the degradation degree of regional habitat quality. The closer the value is close to 1.0000, the higher the habitat degradation degree is. On the contrary, when the value is close to 0.0000, the habitat degradation degree is low.

According to the results shown in Figure 2, the maximum habitat degradation degree in 2000, 2010, and 2020 was 0.2605, 0.2494, and 0.2934, respectively, showing a habitat deterioration trend of first decreasing and then increasing. Considering the influence of the urban construction needs, the degradation of habitat quality rebounded in 2010. The maximum habitat degradation degree in Hohhot City was 0.2934 in 2020, featuring further deterioration, which was mainly attributed to economic development, population growth, and the expansion of urban construction land, as well as increasing attention paid to urban ecological environment protection. From the perspective of spatial distribution, the habitat degradation degree in the surrounding areas of the city was high, and the expansion of construction land had swallowed up cultivated land and ecological land, causing irreversible impact on ecological environment. Among them, the apparent degradation in the mineral land area of Wuchuan County, of course, was also related to the arid climate environment, thereby resulting in the more obvious habitat quality degradation.

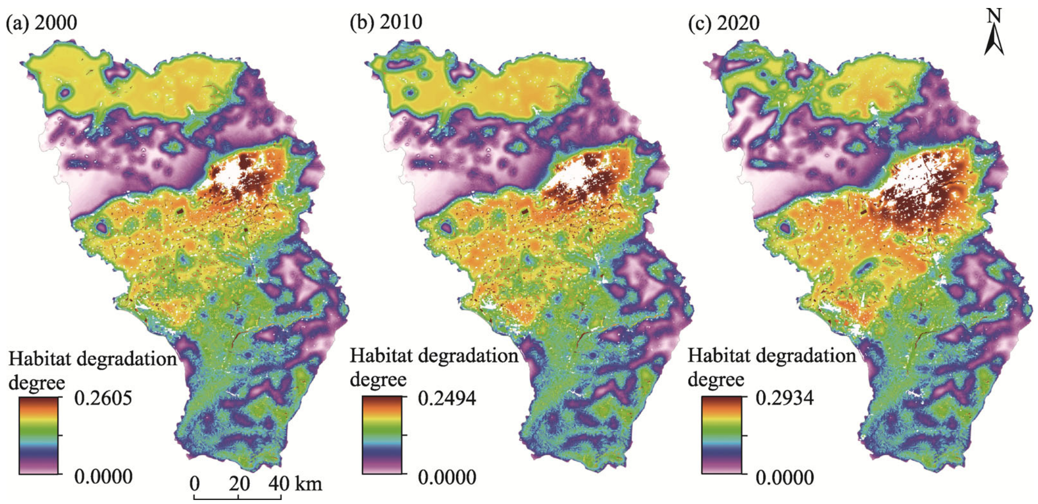

Fig. 2 Spatial distribution of habitat degradation degree in Hohhot City in 2000 (a), 2010 (b), and 2020 (c)

3.3 Habitat quality change

The InVEST model was used to evaluate the habitat quality of Hohhot City in 2000, 2010, and 2020. The range of habitat quality (0.0–1.0) reflects the level of habitat quality. The values close to 1.0 represent higher habitat quality, while values close to 0.0 indicate lower habitat quality. In order to evaluate the impact of land use change on habitat quality during 2000–2020, we divided the habitat quality into five grades: low (0.0–0.2), relatively low (0.2–0.5), medium (0.5–0.7), relatively high (0.7–0.8), and high (0.8–1.0). We calculated the area and proportion of habitat quality in 2000, 2010, and 2020, respectively (Table 5).

Table 5 Area and proportion of habitat quality at different grades in 2000, 2010, and 2020

Grade	Range of habitat quality	2000		2010		2020	
		Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
Low	0.0–0.2	680.44	3.96	756.24	4.41	1070.60	6.24
Relatively low	0.2–0.5	9003.68	52.45	8674.50	50.53	8517.80	49.62
Medium	0.5–0.7	6459.61	37.63	6554.14	38.18	6429.06	37.45
Relatively high	0.7–0.8	888.68	5.18	1062.14	6.19	1048.03	6.11
High	0.8–1.0	134.25	0.78	119.63	0.70	101.18	0.59

The results showed that, from the perspective of temporal scale, the area with low habitat quality was 680.44 km^2 in 2000, accounting for 3.96% of the region area; 756.24 km^2 in 2010, accounting for 4.41%; and 1070.60 km^2 in 2020, accounting for 6.24%. The proportion increased year by year, and the change in the areas of low habitat quality increased gradually. The area of medium habitat quality changed from 6459.61 km^2 in 2000 (37.63%) to 6429.06 km^2 in 2020 (37.45%), and the change in the area of medium habitat quality was relatively stable; in 2000, the area with high habitat quality was 134.25 km^2, accounting for 0.78% of the region area; 119.63 km^2 in 2010, accounting for 0.70%; and 101.18 km^2 in 2020, accounting for 0.59%. The area and proportion of high habitat quality presented a continuously declining trend. The decline in habitat quality is mainly caused by population growth, expansion of urban construction land, and economic development. The average habitat quality in 2000, 2010, and 2020 were 0.3018, 0.3036, and 0.2973, respectively, indicating that the overall habitat quality level was at a low level and in a gradually declining trend.

The change of spatial scale was mainly manifested in the areas where the habitat quality was reduced, such as areas around cities and towns and ecologically fragile areas. From the perspective of spatial evolution, the habitat quality in central urban areas, such as Wuchuan County, Tumed Left Banner, and Horinger County was relatively low, which was related to natural factors such as geological and geomorphic conditions and the climate in the region, as well as human factors leading to the destruction of forests and grasslands. To sum up, the overall habitat quality in Hohhot City showed a gradually descending trend, mainly characterized in areas such as the central urban area and ecologically fragile areas. In general, it was restricted by urban expansion, population growth, and climate conditions, as well as other natural, economic, and social factors.

3.4 Prediction of land use change pattern

The land use data of Hohhot City in 2000, 2010, and 2020 were used for analysis and the CA-Markov model was applied in IDRISI 17.0 software to predict the land use evolution in 2030. Before the simulation, the data of land use planning were considered and the simulation results were verified by Kappa coefficient. Through the test of IDRISI software, the Kappa coefficient value is predicted to be 0.8103 in 2030 (generally, when the Kappa coefficient is greater than or equal to 0.75, it is considered that the simulation prediction accuracy is high (Pan et al., 2018)). Thus, the simulation of land use change passed the accuracy test.

According to the simulation results (Fig. 3; Table 6), the fluctuation of cultivated land, grassland, and wetland was still obvious. The change of cultivated land was –1335.36 km^2, with a change rate of –0.01%; the change of grassland was –266.26 km^2; and the change of wetland was –45.17 km^2, with a change rate of –0.06%. The change rates of forest, shrubland, water body, artificial surface, and bareland were 0.04, 0.42, 0.03, 0.12, and 0.01, respectively. It can be seen that artificial surface was still the main land in 2030. Besides, the future urban construction needs and economic development needs will lead to significant land use changes in 2030.

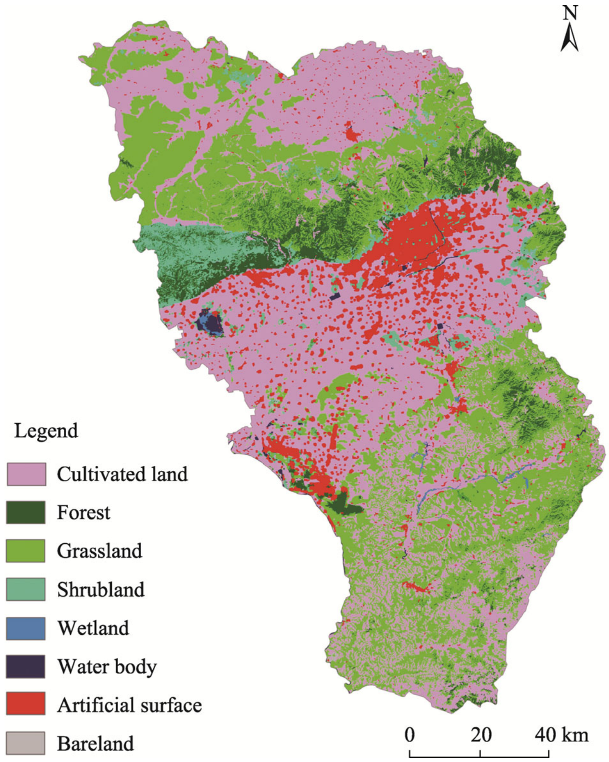

Fig. 3 Prediction of land use change pattern in Hohhot City in 2030

Table 6 Land use change prediction in Hohhot City during 2020–2030

Land use type	Predicted area in 2030 (km^2)	Area in 2020 (km^2)	Change in area between 2020 and 2030 (km^2)	Rate of change (%)
Cultivated land	7675.20	9010.56	–1335.36	–0.01
Forest	1202.72	887.62	315.10	0.04
Grassland	6061.19	6327.45	–266.26	0.00
Shrubland	700.83	134.19	566.64	0.42
Wetland	29.06	74.23	–45.17	–0.06
Water body	78.27	62.26	16.01	0.03
Artificial surface	1391.00	644.78	746.22	0.12
Bareland	28.39	25.59	2.80	0.01

3.5 Prediction of habitat degradation degree

Based on the CA-Markov model and the InVEST model, we mapped the simulation prediction of habitat degradation degree in Hohhot City (Fig. 4). The simulation results in Figure 4 were highly similar to the evolution of habitat quality from 2010 to 2020 and the overall simulated average habitat quality index value was 0.2949, presenting a continuous downward trend. The area with low habitat quality was 1431.78 km^2, accounting for 8.34%; the area with medium habitat quality was 6762.86 km^2, accounting for 39.40%; and the area with high quality was 95.10 km^2, accounting for 0.55%. The areas with low quality and high quality accounted for a relatively small proportion, while the medium habitat quality still occupied the dominant position, which reflected that considering the constant declining of the overall habitat quality, the spatiotemporal evolution of habitat quality in Hohhot City is still not optimistic. In the case of future development, attention should be paid to the coordinated measures between urban development and environmental protection.

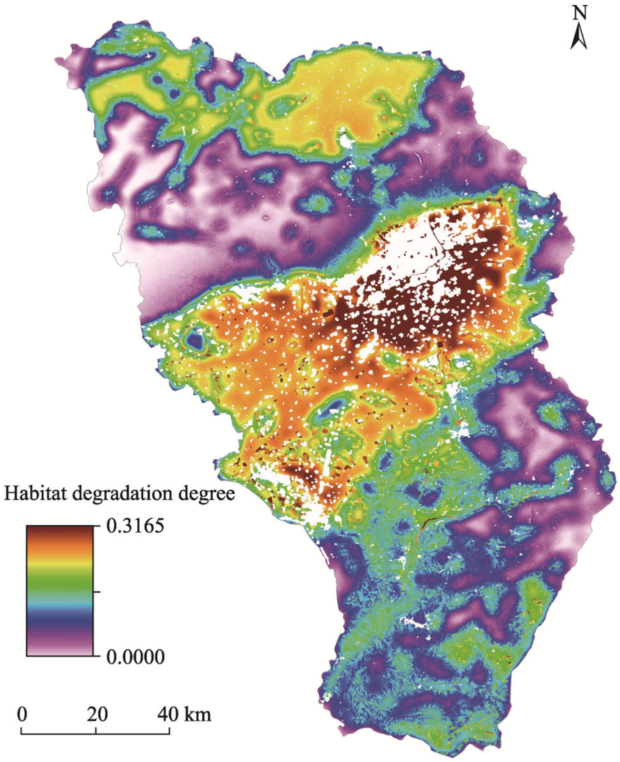

Fig. 4 Prediction of habitat degradation degree in Hohhot City in 2030

4 Discussion

4.1 Spatiotemporal characteristics of habitat quality and land use pattern

Due to the application of different data sources, study periods, and quantification methods, this study is significantly different from other published results. Meanwhile, it is hereby found that urban disorderly expansion is the direct cause of land use change and ecological environment mutation, which is consistent with previous studies (Ma et al., 2020; Bai et al., 2022; Cai et al., 2022). However, the existing research results on land use change in Hohhot City mainly focus on the evaluation of the land use unitary index (Fan, 2014; Tong, 2014; Zhao, 2021). In order to improve the quality of urban residential environment in the process of urban construction and promote the coordinated sustainable urban development and natural environment, we analyzed the evolution rules and influencing factors of urban space from the perspective of urban land use, and predicted the future development direction of Hohhot City through simulation. The research results provide certain reference value for regional urban ecological environment quality evaluation.

The impact of land use change on habitat quality in Hohhot City in 2000, 2010, and 2020 was hereby obtained by setting the indicators of threat factors and habitat sensitivity factors. From 2000 to 2020, the land transfer changed frequently, and the factors affecting land use change were complicated (Gao et al., 2018; Li and Kuang, 2019; Cheng et al., 2020). It is confirmed that the urban expansion pattern from inside to outside causes land use change to affect urban habitat quality, which is consistent with studies on the continuous polarization of land urbanization caused by the urbanization change of population and the expansion and change of cities from inside to outside (Wang et al., 2019; Wang, 2022; Zhu et al., 2022).

From 2000 to 2020, the land use change showed that cultivated land, forest, and grassland were the main land use types, which were converted into artificial surface, thus resulting in the continuous reduction of ecological land. Then, the INVEST model was used to evaluate the quality of urban habitat, and the CA-Markov model was used to simulate the land use change in 2030. It was found that cultivated land, shrubland, and grassland were decreasing, and artificial surface was expanding continuously, which is consistent with the planning development direction of urban form (Liu and Xin, 2022; Lou et al., 2022; Wang et al., 2022). Land use change is influenced by geographical region factors, natural conditions, and other factors, which limit land use transfer and change.

4.2 Impact of land use pattern change on habitat quality

The habitat quality index of Hohhot City in 2000, 2010, and 2020 was analyzed using the InVEST model. The results showed that the habitat quality of Hohhot City presented a continuous decline trend. The InVEST model was used to evaluate the habitat quality in Hohhot City at the macro scale, and it is found that cultivated land is the main type for urban construction. The city construction land expansion, urban ecological environment quality, and land use decoupling dissimilation phenomenon were presented (Li et al., 2020; Zhang et al., 2020; Liu and Lu, 2022). The increased demand for urban construction land has resulted in unreasonable land use and caused serious ecological and environmental problems. Affected by natural disasters, the city habitat quality continues to decline (Wang et al., 2017; Zhou et al., 2017).

By simulating the land use change in Hohhot City in 2030, economic development, population growth, and urban construction were found to have significant effects on habitat quality change. In order to solve the inefficient and excessive land use pattern, it is necessary to strengthen the regulation from the link of supply and demand and geographical location, release the non-urban functional land, relieve the growth pressure of urban land use, improve the construction area of urban green space, solve the dilemma of inefficient land use, and alleviate the problem of habitat quality decline affected by land use change. In addition, by analyzing the spatiotemporal evolution of habitat quality, it was also found that the improvement of habitat quality in 2010 was related to the urban construction needs of returning farmland to forest at that time (Li et al., 2022; Zheng and Li, 2022). The CA-Marcov model was used to predict the land use change in 2030, and it was found that the area of land use expansion was around the urban area, which also verified that the land use change expanded around the central urban area and showed a trend of point-to-plane change. It also indicated that urban land use change was affected by urban construction need, and it also showed a certain spatial heterogeneity, which is consistent with existing research results (Niu et al., 2022; Weldesilassie and Worku, 2022; Zhou et al., 2022).

4.3 Limitations and future prospects

The research data were downloaded from the National Geographic Information Center, and the raster data was trimmed, spliced, and verified, which might lead to the low accuracy of the research data. Besides, the sensitive sources, threat factors, and weight selected in the research method are still subjective to a certain extent, although they refer to the research results of neighboring regions (Li et al., 2022). The research results are still subject to some limitations caused by the selection of data and research methods. In future research, more representative factors and more scientific methods should be selected from data, research methods, and evaluation factors, and other qualitative and quantitative evaluation methods should be integrated, so as to improve the evaluation methods and techniques and obtain the evaluation results with guiding significance.

5 Conclusions

Land use change is one of the main factors affecting the evolution of habitat quality. In order to scientifically deal with the coordination between environmental quality change and urban development, we carried out this study in Hohhot City using the CA-Markov model and the InVEST model. Firstly, the results showed that the regional land use types in Hohhot City changed significantly from 2000 to 2020. Urban expansion was the main factor leading to the degradation of habitat quality. However, land use change was the main form leading to the change of urban habitat quality. According to the land change and transfer matrix from 2000 to 2020, the cultivated land was the main transfer type of urban construction land. Then, it was found that the habitat degradation degree was affected by stress habitat factors, which can explain the degradation degree of regional habitat quality. According to the natural, social, and economic development of the city and other factors, scientific land space planning can achieve the integration of multiple urban planning. In addition, based on land use change in Hohhot City during 2000–2020, the habitat quality showed a declined tendency. Finally, according to the prediction of land use evolution, habitat quality will continue to decline, and artificial surface will still be the main land use type in 2030. Therefore, it should be considered to strengthen the protection of ecological environment, improve the quality of living environment, and limit the disorderly expansion of urban boundaries in the planning of territorial space, so as to achieve the harmonious development of human and nature.

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