Research Paper

Kunming urban habitat quality assessment and spatiotemporal prediction coupled with FLUS-Invest model

Keqing Qu, School of Architecture, Harbin Institute of Technology, Key Laboratory of Cold Region Urban and Rural Human Settlement Environment Science and Technology, the Ministry of Industry and Information Technology, Harbin, China;

Abstract

This paper have taken Kunming City as a research case, combined FLUS model with InVEST model based on 30-meter land cover data in 2000 and 2020, established a coupling model of land use change and habitat quality. The model can be used to predict and simulate future habitat quality based on future land use change. The results are as follows:(1) The area of construction land, water bodies and wetlands in Kunming increases slightly from 2000 to 2020, the area of forest land and grassland decreases slightly, while the area of cropland continues to decrease by rapid developing impervious surface from cropland and grassland. (2) It uses the FLUS model to predict the land use change under the two scenarios of natural evolution and ecological protection. Under the natural evolution scenario, the change is basically the same as that in 2000-2020, while significantly reducing the intensity of land use change. Under the ecological protection scenario, the expansion trend of impervious surface slows down strongly, while the forest land increases significantly. (3) The calculation results of habitat quality show that the habitat quality in the watershed is polarized from 2000 to 2020 with the overall level on a downward trend. From the perspective of the pattern, the areas with declining habitat quality are mainly concentrated in the construction land around Dianchi Lake. (4) Under the two predicted scenarios, the habitat quality of the ecological protection scenario increases by 1.06% compared with 2020, which is 3.39% higher than that of the natural evolution scenario.

Keywords

Land use;FLUS model ;Habitat quality ;InVEST model

1. Introduction

Human production and lifestyle have undergone drastic changes in the process of global urbanization, since urbanization has also drastically changed the types of land use, resulting in habitat fragmentation, functional degradation and even loss, triggering a biodiversity crisis (Falcucci,2007;Hu,2013). Land use change can directly connect human activities with the evolution of the natural environment, reflecting the process and intensity of human eco- transformation（Yuan,2008）. Habitat quality refers to the ability of an ecosystem with suitable individuals and populations for applicable development and survival, which can reflect regional biodiversity to a certain extent (Hillard,2017). Therefore, analyzing the temporal and spatial change characteristics of land use can further explore the laws and causes of habitat quality changes, which plays an important role in the protection of biodiversity and the sustainable use of land resources(Wei,2016).

The FLUS (Future Land Use Simulation) model integrates the artificial neural network algorithm when the adaptive inertial competition mechanism of roulette can effectively deal with the uncertainty and complexity of land conversion under natural and human factors(Liu,2017). The FLUS model can couple the influence of human activities and natural environment factors, simulate the interaction of various land types in the regional space, and calculate the distribution of future land use with high precision (Liang,2018). At present, the FLUS model has been studied in many scales, including carbon storage(Liu,2019), ecological space(Wang,2020), hydrological(Luo,2019) or land-use change(Zhang,2019). However, it has limited combination of FLUS model and habitat quality assessment to predict the effect of ecological restoration under the national spatial planning guide. Assessing habitat quality while simulating and predicting the changing trend of habitat quality are of great significance for studying human well-being, maintaining global health, and promoting regional sustainable development.

Therefore, by integrating the FLUS and InVEST models, this paper analyzes the current land use data in Kunming from 2000 to 2020, so as to explore the evolution of land use change and habitat quality. According to the laws and regional development goals, it selects the adaptive driving factors based on the FLUS model, then uses the two development directions of natural evolution and ecological protection planning to simulate land use changes in scenarios, so as to predict the future temporal and spatial pattern of habitat quality. To propose a habitat quality prediction model based on the FLUS-InVEST framework, explore the evolution mechanism of land use and habitat quality, it can provide scientific reference for urban ecological environment governance and protection for promoting high-quality development of local ecological environment.

2. Method

2.1. Study area and study data

Kunming City (102°10′-103°40′E, 24°23′-26°33′N) is located in southwestern China, in the middle of the Yunnan-Guizhou Plateau, and is the capital of Yunnan Province. The total area of the city is 21,473km^2, and the built-up area is 483.52km^2. It has 7 districts, 3 counties, 1 county-level city and 3 autonomous counties under its jurisdiction. Kunming has a northern subtropical low-latitude plateau mountain monsoon climate, with typical temperate climate characteristics, the lowest annual temperature difference in the country, and the urban temperature is between 0 and 29 °C. It is known as the "Spring City". The landform types are mainly plateaus and mountains and hills, with an altitude of 1500-2800m. The overall terrain is high in the north and low in the south, and gradually decreases from north to south. Kunming is at the heart of the development of our south-western region, the gateway to the south-western part of our country, and an important part of the construction of the ecological barrier in central Yunnan, or regional environmental protection, the development of Kunming is one of its pillars(Wang,2013;Wu,2019).

However, Kunming City has formed a development model centered on Dianchi Lake. According to the 2019 Kunming statistical yearbook, the city's total population reached 6.95 million in 2019, with a well-developed population （Kunming Bureau of Statistics,2019）.With the growth of population, the expansion of cities and the development of industry and agriculture around the lake, the urbanization process and the rapid population growth in the Dianchi Lake Basin, along with the intensification of human activities in the surrounding lake basin(Chen,2019). The resources of the Dianchi Lake Basin are over-exploited and utilized, the types of land use change frequently, and the quality of the habitat is degraded day by day, causing huge social, economic and ecological losses to the local area.

2.2. Data sources

(1) Land cover data: Remote sensing land cover data (2000, 2010, 2020, 30m*30m) obtained from the global 30-meter surface cover fine classification product of Liu Liangyun's team. This product follows the classification system of the 2020 benchmark data and includes a total of 29 types of land cover (https://data.casearth.cn/). In this study, land use types were reclassified into six categories: cropland, forest, grassland, water body, bare areas, impervious surface, wetland.

(2) Digital elevation model data: The original high-resolution product data of the Advanced Land Observing Satellite-1 (ALOS) of the Japan Aerospace Exploration Institute (JAXA) includes: UTM projected 12.5m terrain GeoTIFF (https ://alos-pasco.com/)

(3) Meteorological observation data: from China Meteorological Data Network (http://data.cma.cn/), precipitation data (2000, 2010, 2020, 30m*30m) from the National Science and Technology Basic Conditions Platform— National Earth System Science Data Center (http://www.geodata.cn)

(4) Social and economic data: GDP data comes from the GDP spatial distribution dataset (2000, 2020, 1km*1km) of China's resource and environmental data cloud platform, expressed in units of 100,000 yuan/km^2. (http://www.resdc.cn/) Population data (2000, 2020, 100m*100m) comes from the Open Access and Application Organization of Population Data under the University of Southampton (https://www.worldpop.org/)

(5) Statistical data:Kunming Statistical Yearbook 2000, Kunming Statistical Yearbook 2020 (http://www.mwr.gov.cn/)

2.3. Research methods

2.3.1 Prediction based on FLUS model

The FLUS model is used to simulate the current land use change or future land use scenarios under the interaction of human activities and natural factors. First, use artificial ANN (Neural Network Algorithm) combined with driving factors (topography, traffic, economy, etc.) to calculate the suitability probability of land use type of each cell unit, that is, each land use type in the study area is on each pixel probability of occurrence(Jia,2012). An adaptive inertial competition mechanism is included in the model, including neighborhood influence factors, inertial coefficients, and conversion costs(Sohl,2010). Together they affect the joint probability of future land-use change outcomes(Liang,2018). The model derives the simulated land use types by running CA (cellular automata)(Ward,2000) . Finally, the roulette mechanism is used to assign the land type of each grid cell, so that the initial land type is converted into a land type with a smaller joint probability(Liang,2018). The FLUS model can reflect the uncertainty and complexity of the mutual transformation of land use change types under natural and human activities, and the simulation accuracy is higher, and the Kappa index can be used to verify the validity(Altan,2021).

2.3.2 Habitat quality assessment method based on InVEST

This paper uses the Habitat Quality module of the InVEST model to assess habitat quality. Habitat quality reflects the various resources and conditions that the environment provides for the survival and development of individuals or populations(Yohannes,2021). When the habitat quality is good, the resource environment is not damaged, and the biodiversity can be guaranteed and developed. The habitat quality module introduces the disturbance of human activities into the evaluation of habitat quality(Terrado,2016). When human activities are intensified, the level of habitat quality will decrease significantly. The working principle of the model is to combine the external threat factors and their intensity, and the second is to calculate the habitat quality score based on the sensitivity of each land use type to the threat factors(Valero,2015). Usually habitat quality results range from 0 to 1.

The formula for habitat quality is:

$$Q_{ik} = H_k\left(1 - \frac{M_{ik}^z}{M_{ik}^z + K^Z}\right) \quad (1)$$

$$M_{ik} = \sum_{r=1}^{R}\sum_{y=1}^{Yr}\left(\frac{w_r}{\sum_{r=1}^{R} w_r}\right) r_y i_{rxy} \beta_x S_{kr} \quad (2)$$

In the formula: Q_{ik} is the habitat quality of the land type at the space unit i, between 0 and 1, the higher the value, the better the habitat quality; Hk is the habitat suitability of the land type k; M_{ik} is the habitat degradation at the space unit i degree; z is the default parameter of the model, with a value of 2.5; k is the half-saturation coefficient, usually taking 1/2 of the maximum habitat degradation degree; R is the number of threat factors; w_r is the weight of the threat factors; Y_r is the number of units of the threat layer in the terrain layer; r_y is the intensity of the threat factor; i_{rxy} is the threat level of the threat factor to the habitat; is the degree of legal protection; S_{kr} is the sensitivity of the land type k to the threat factor.

2.3.3 Research framework and multi-scenario setting

Based on the land use data in 2000, the FLUS model was used to simulate the land use data in 2020. Through the comparison of various factors, 10 driving factors including elevation, slope, slope aspect, precipitation, distance to river, distance to city center, distance to railway, distance to main road, population density and GDP distribution were selected, and The simulation is carried out with water as the limiting factor. Based on the data in 2020, the land use types were fitted with a number of spatial driving factors, and the suitability probabilities of various land use types in Kunming within the research range in 2040 under the two scenarios were calculated. Finally, through the habitat quality module of the InVEST model, the habitat quality of the two scenarios in 2000, 2020 and 2040 was assessed and divided into five levels.

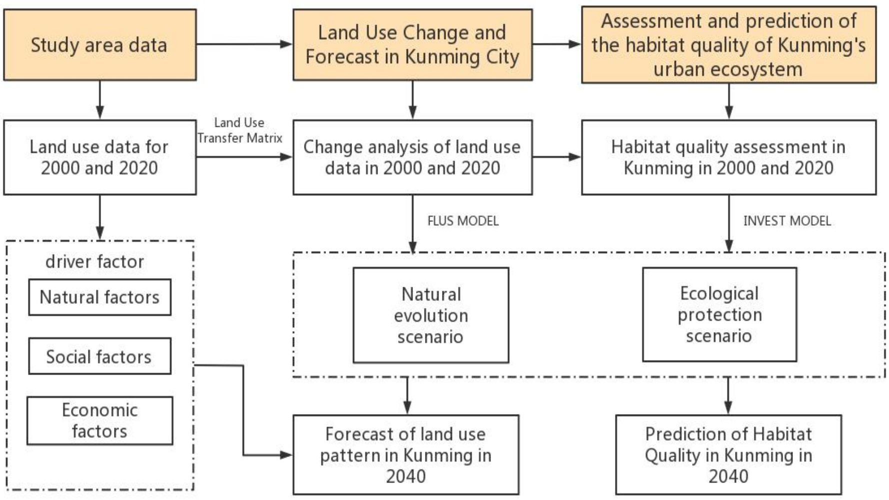

Figure 1. Research Framework.Source:Self-drawn by the author.

On the basis of other related papers, the neighborhood factor parameters are fine-tuned and multiple experiments are performed to set and adjust neighborhood weights in different scenarios (Table 1). This paper predicts land use changes based on environmental impact factors. Based on the current expansion of the city and Kunming's urban development and ecological protection policies, it is divided into two scenarios: natural evolution scenario (A) and ecological protection planning scenario (B).

Table 1. Neighborhood factor parameter.Source:From the author's experiments.

Land type	Neighborhood weight(A scenario)	Neighborhood weight(B scenario)
Cropland	0.7	0.6
Forest	0.3	0.3
Grassland	0.4	0.4
Water body	0.5	0.55
Bare areas	0.7	0.4
Unimpervious surface	0.9	0.7
Wetland	0.5	0.55

3. Result

3.1. Space-time evolution of land use based on FLUS model

3.1.1. Characteristics of current land use temporal and spatial pattern

The land use in Kunming City is dominated by forest and grassland, accounting for more than 80% of the total area (Figure 2). After 20 years of changes, impervious surface has grown the most among all local categories, with an increase of 96%. Other land types have different rates of increase or decrease. Cropland, forest, and grassland are all in a state of decline. However, due to the active implementation of reservoir construction and river basin ecological governance policies, the area of water and wetland has increased.By calculating the land use transfer matrix (Table 2), we tried to discover the land type transfer law. The research shows that among all land use types in Kunming from 2000 to 2020, the highest amount of transfer out is grassland, and the most obvious is conversion to forest. The impervious surface with the largest area increase among all types is mainly transformed from cropland and grassland. The most obvious is the conversion of cropland into grassland, accounting for 26.38% of the original cropland area. Due to the rapid expansion of human activities, the distribution pattern shows a trend of extending outward along the periphery of the Dianchi Lake basin of the plateau lake.

	2020a							
2000a	Bare areas	Cropland	Forest	Grassland	Impervious surface	Water body	Wetland	Total area
Bare areas	11	9	0	13	11	1	0	45
Cropland	22	121546	19503	61414	29348	935	33	232801
Forest	2	22991	804730	133895	5558	1430	64	968670
Grassland	49	63036	137159	576632	26723	2394	29	806022
Impervious surface	6	4976	860	4889	42332	145	3	53211
Water body	0	713	1090	1254	317	37378	37	40789
Wetland	0	22	35	14	7	38	15	131
Total area	90	213293	963377	778111	104296	42321	181	2101669

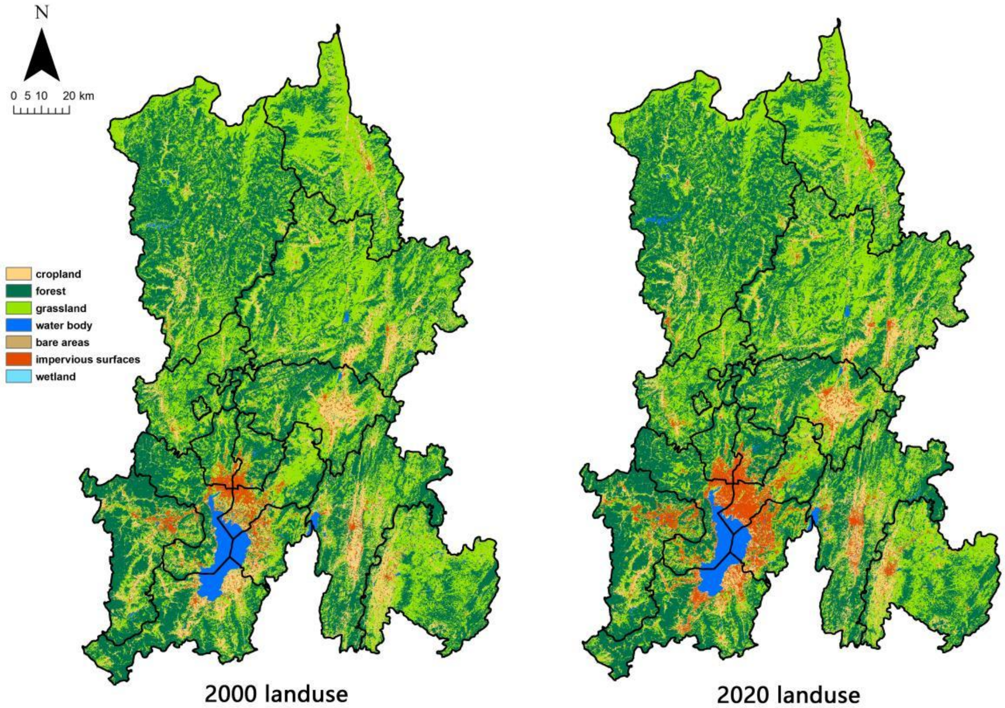

Figure 2. Land use pattern of Kunming in 2000 and 2020.Source:(https://data.casearth.cn/).

Table 2. Transfer matrix of land use types in Kunming from 2000 to 2020（hm²）,Source:Self-drawn by the author.

3.1.2. Temporal and spatial evolution of land use under two scenarios

The land use data in 2020 was simulated by the land use data in 2000, and the results were similar to the real data in 2020. The Kappa coefficient is 0.89, the simulation effect is good, and the reliability is high. At the same time, the FOM index is 0.12, and the FOM index is usually affected by the number of simulation years and is at the standard level. Based on the land use data in 2020, the land use changes under the three scenarios of natural development (A) and ecological protection (B) are predicted.

Under Scenario A, the spatial pattern of land use will continue the existing characteristics of land use change, and construction land still has the largest increase among various land use types, but the growth has slowed down, increasing by 23.15%. Among other land use types, water bodies and forests increased slightly, and all other land use types decreased. The highest amount of transfer is forest, and the most significant transfer is grassland. Impervious surface continues to expand to cropland and grassland with the Dianchi Lake Basin as the urban core; the amount of cropland transferred out is the highest, reaching 11.86% of the original cropland area. However, due to the implementation of the basic cropland protection policy, the amount of cropland transferred out has been reduced. Grassland is mainly turned to; water body, wetland, bare areas have a small turn in and are in a relatively stable state. Under Scenario B, the land use pattern is different from Scenario A. Wetland became the land use type with the largest increase, with an increase of 29.28%. Forests, water bodies, and impervious surfaces all increased, while grassland, cropland, and bare areas decreased. The increase of impervious land only reached 18.08% of the A scenario, which limited the trend of impervious surface expansion, and partially carried out ecological restoration. The amount of cropland transferred out reached 11.06% of the original cropland, and the amount of transfer out was still limited by the cropland protection policy. The bare areas is almost turned out to a null value, and the unused land has been successfully exploited. The increase of water wetlands has become larger, mainly from grassland.

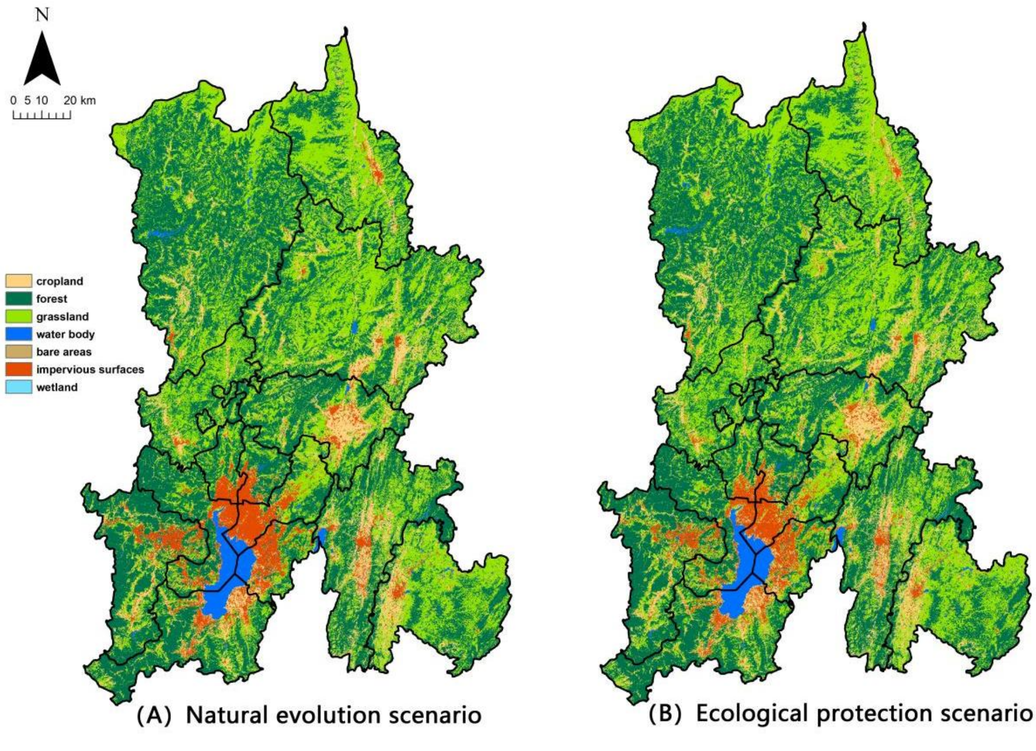

Figure 3. Future scenario simulation of land use pattern in 2040.Source:Self-drawn by the author.

3.2. Habitat Quality Assessment

3.2.1. Current Habitat Quality Assessment Characteristics

Based on real land use data and predicted multi-scenario land use data, this study selects cropland, construction land, and unused land as threat sources according to the actual situation in Kunming (Table 3), and sets other parameters in combination with relevant literature and regional characteristics (Table

4). Through the habitat quality module of the InVEST model, the results of the multi-period habitat quality of Kunming can be obtained. The habitat quality results range from 0 to 1, and the closer the habitat quality is to 1, the stronger the ability of the region to resist threats, and the better the habitat quality. According to the results of the habitat degradation degree obtained by the InVEST model, through the natural breakpoint method, the Kunming urban habitat quality is divided into five grades in equal intervals from small to large: lowest (0.0 - 0.3), lower (0.3 - 0.5); Moderate (0.5 - 0.7), High (0.7 - 0.9), Highest (0.9 - 1.0).

Judging from the real data from 2000 to 2020, the area distribution of different levels of habitat quality assessment is significantly different, and the trend of polarization is obvious. Luquan District has the best habitat quality, and Chenggong District and Guandu District have the most obvious habitat quality degradation. As of 2020, the area of the Lowest habitat quality area has increased by 316.05km^2, accounting for an increase of 11%. The lower habitat quality area covers less than 1% of the total area, but the growth is the most dramatic, accounting for an increase of 99.98%. The area of medium habitat quality area increased by 38.17%. Higher quality habitat area decreased by 276.62km^2, accounting for a decrease of 3.43%. Highest quality habitat area decreased by 0.40%. The average habitat quality in 2000 was 0.7866, and the average habitat quality in 2020 was 0.7734, a decrease of 1.68%, but the overall habitat level was still above the middle. The distribution pattern of habitat quality shows a differentiation pattern of high in the north and low in the south. The human development space around the northeast of the Dianchi Lake Basin and the cropland areas of Songming County, Yiliang County and Shilin County belong to the area with the lowest habitat quality. The habitat degradation degree of Impervious surface is almost close to 0, because the land use type of the built-up area is difficult to change; the surrounding areas close to the urban land will be affected by the expansion of the town, and the habitat degradation degree is mainly low and moderate; , wetland and other land types are in a slightly degraded state due to planning restrictions and protection.

Table 3. Threat source weight and maximum influence distance.Source:From the author's experiments.

MAX_DIST	WEIGHT	THREAT	DECAY
4	0.2	crop	linear
8	0.2	bare	linear
10	1	urban	exponential

Table 4. Sensitivity of land types to threats.Source:From the author's experiments.

LULC	NAME	HABITAT	L_crop	L_built	L_bare
1	Cropland	0	0	0	0
2	Forest	1	0.7	0.6	0.5
3	Grassland	0.8	0.6	0.7	0.6
4	Water body	1	0.8	0.6	0.7
5	Bare areas	0.5	0.4	0.5	0.4
6	Impervious surface	0	0	0	0
7	Wetland	0.7	0.8	0.7	0.8

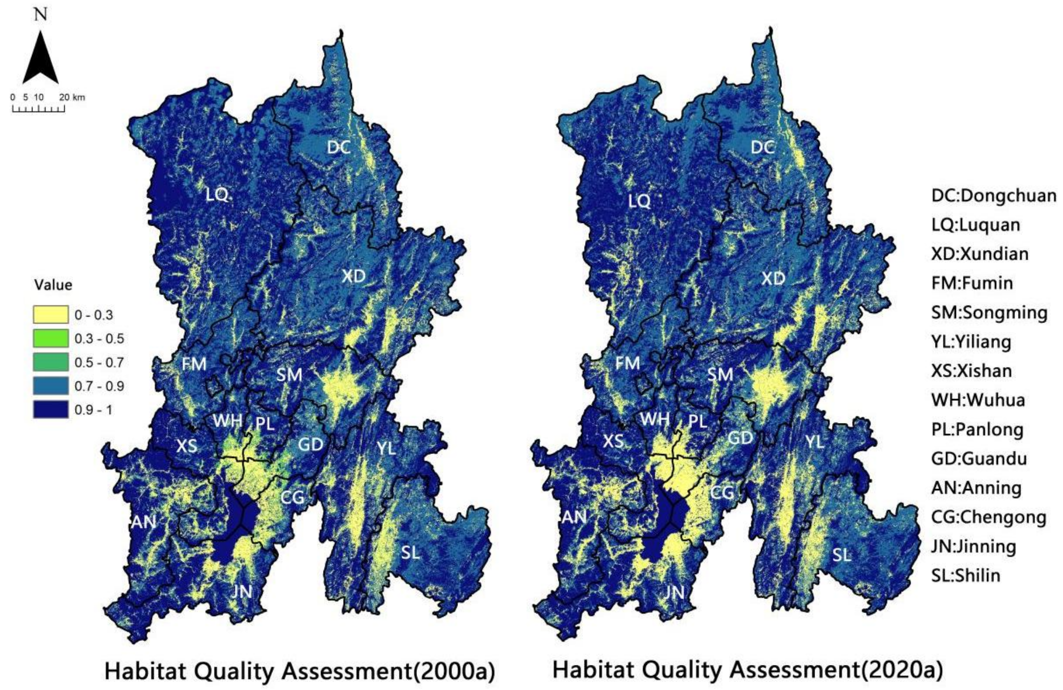

Figure4. Spatial and temporal patterns of habitat quality assessment.Source:Self-drawn by the author.

3.2.2. Spatial and temporal evolution of habitat quality under two future scenarios

(1) Under the natural evolution scenario, the average habitat quality of the whole region in 2040 is 0.7560, which is 2.25% lower than that in 2020. The lowest quality habitat increased by 2.85%, the lower quality increased by 28.57%, the medium quality increased by 7.10%, the higher quality increased by 3.58%, and the highest quality habitat decreased by 2.68%. The basic pattern of habitat quality The central urban area surrounding the plateau lake is still expanding, and the habitat near the urban area is degraded significantly. The average habitat quality in Luquan District was the highest with a value of 0.8707, and the average habitat quality in Chenggong District was the lowest with a value of 0.5295.

(2) Under the ecological protection scenario, the average habitat quality is 0.7816, an increase of 1.06% over 2020 and 3.39% higher than scenario A. The overall development trend is quite different from the natural evolution scenario. Because of the implementation of ecological protection policies, the minimum quality is 4.54% lower than the habitat assessment results in 2020, and 5.32% lower than Scenario A. Lower-quality habitats decreased by 22.22% from the 2020 assessment results. The medium-quality habitat increased by 29.28% compared with the 2020 assessment results, and increased by 38.46% compared with Scenario A. Higher quality habitats increased by 1.70% compared to the 2020 assessment results. The highest quality habitats increased by 2.75% from the 2020 assessment results. In general, there is a trend of decreasing low-quality habitats and increasing high-quality habitats. Luquan District had the highest average habitat quality at 0.8759, 0.60% higher than scenario A, and Chenggong District had the lowest average habitat quality at 0.5447, 2.88% higher than scenario A.

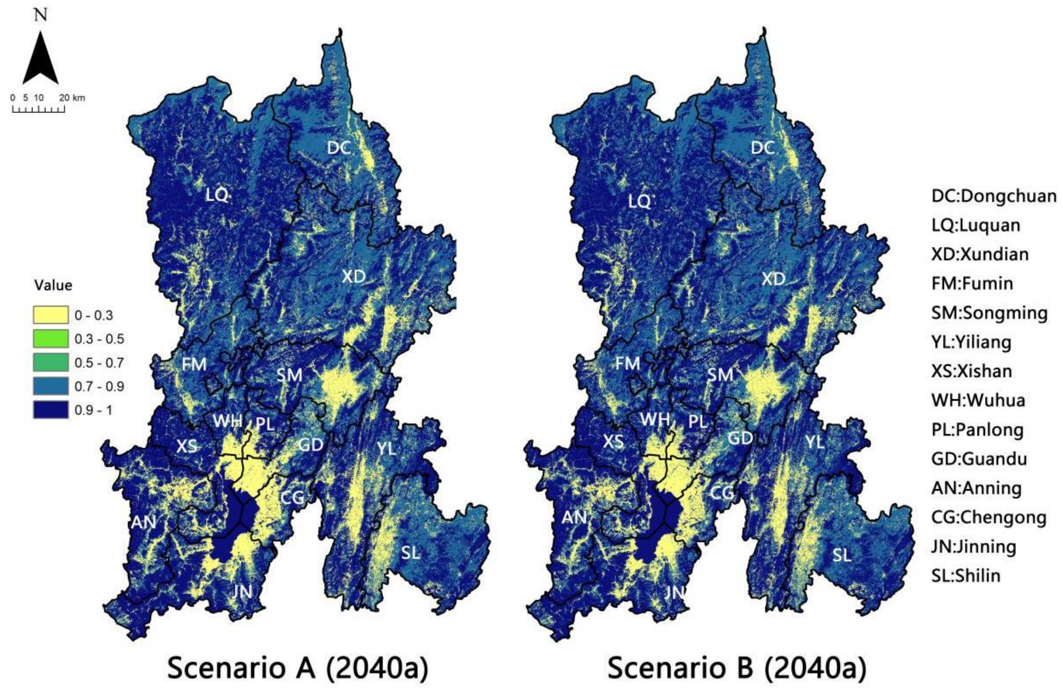

Figure 5. Spatial and temporal patterns of habitat quality under different scenarios..Source:Self-drawn by the author.

4. Discussion and conclusion

This paper combines the FLUS model and the InVEST model to establish a coupled model of land use change and habitat quality, which can predict future land changes based on current land use data. Based on the future land use change, the habitat quality can be predicted and simulated more accurately. The research results show that: (1) The area of construction land, water bodies and wetlands in Kunming increases slightly from 2000 to 2020, the area of forest land and grassland decreases slightly, while the area of cropland continues to decrease by rapid developing impervious surface from cropland and grassland. (2) It uses the FLUS model to predict the land use change under the two scenarios of natural evolution and ecological protection. Under the natural evolution scenario, the change is basically the same as that in 2000-2020, while significantly reducing the intensity of land use change. Under the ecological protection scenario, the expansion trend of impervious surface slows down strongly, while the forest land increases significantly. (3) The calculation results of habitat quality show that the habitat quality in the watershed is polarized from 2000 to 2020 with the overall level on a downward trend. From the perspective of the pattern, the areas with declining habitat quality are mainly concentrated in the construction land around Dianchi Lake. (4) Under the two predicted scenarios, the habitat quality of the ecological protection scenario increases by 1.06% compared with 2020, which is 3.39% higher than that of the natural evolution scenario. This conclusion fully shows that habitat quality will be significantly improved under ecological planning.

It depicts the early urban planning of Kunming City around the Dianchi Lake Basin, and the construction land expanded outwards in a disorderly manner, resulting in an unreasonable land use structure, excessive population aggregation, and serious damage to the habitat space. According to the conclusion, the continuous low-density land expansion shall be paused to further slow down the trend of habitat degradation and improve the regional ecological environment conditions, then control the scale of urban land use reasonably. Meanwhile, it adoptes appropriate ecological protection policies tocarry out the ecological restoration of land space in an orderly manner. In the future planning, it is necessary to rationally design the urban housing system, promote the intensive use of land; strengthen the linkage of urban and rural transportation, change the single layout around Dianchi Lake, build a new urban and rural framework. By simulating future land use scenarios in the Plateau Lake Basin, and calculating the characteristics of changes in habitat quality patterns in the future, it constructs a logical perspective connecting "past-present-future", which is of great significance for scientifically managing ecosystems and promoting optimal resource allocation.

4. References

Chen, J., Jiang, B., Bai, Y., Xu, X. & Alatalo, J.M. (2019) 'Quantifying ecosystem services supply and demand shortfalls and mismatches for management optimisation', *Science of the Total Environment,* 650, p1426-1439.

Chen, Z., Huang, M., Zhu, D. & Altan, O. (2021) 'Integrating remote sensing and a markov-FLUS model to simulate future land use changes in Hokkaido, Japan', *Remote Sensing,* 13(13), p2621.

Falcucci, A., Maiorano, L. & Boitani, L. (2007) 'Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation', *Landscape Ecology,* 22(4), p617-631.

Hillard, E.M., Nielsen, C.K. & Groninger, J.W. (2017) 'Swamp rabbits as indicators of wildlife habitat quality in bottomland hardwood forest ecosystems', *Ecological Indicators,* 79, p47-53.

Hu, X., Wu, C., Hong, W., Qiu, R. & Qi, X. (2013) 'Impact of land-use change on ecosystem service values and their effects under different intervention scenarios in Fuzhou City, China', *Geosciences Journal,* 17(4), p497-504.

Kunming Bureau of Statistics, M. (2019) Kunming Statistical Yearbook. 1st. Beijing: China Statistics Press.

Liang, X., Liu, X., Li, D., Zhao, H. & Chen, G. (2018a) 'Urban growth simulation by incorporating planning policies into a CA-based future land-use simulation model', *International Journal of Geographical Information Science,* 32(11), p2294-2316.

Liu, X., Liang, X., Li, X., Xu, X., Ou, J., Chen, Y., Li, S., Wang, S. & Pei, F. (2017) 'A future land use simulation model (FLUS) for simulating multiple land use scenarios by coupling human and natural effects', *Landscape and Urban Planning,* 168, p94-116.

Liu Xiaojuan, Li Xia, Liang Xun, Shi Hong, Ou Jinpei. (2019) 'Simulation of future land use change and its impact on carbon stock in China based on FLUS-InVEST model', Tropical geography, 39(3), p397-409.

Lu, J. & Guldmann, J.-M. (2012) 'Landscape ecology, land-use structure, and population density: Case study of the Columbus Metropolitan Area', *Landscape and Urban Planning,* 105(1-2), p74-85.

Luo, M. , & Li, X. . (2019). Forest Loss Simulation and Water Yield Assessment Based On GEOSOS-FLUS Model: A Case Study of Yangtze River Delta and Pearl River Delta. *IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium*.

Sohl, T.L., Loveland, T.R., Sleeter, B.M., Sayler, K.L. & Barnes, C.A. (2010) 'Addressing foundational elements of regional land-use change forecasting', *Landscape Ecology,* 25(2), p233-247.

Terrado, M., Sabater, S., Chaplin-Kramer, B., Mandle, L., Ziv, G. & Acuña, V. (2016) 'Model development for the assessment of terrestrial and aquatic habitat quality in conservation planning', *Science of the Total Environment,* 540, p63-70.

Valero, E., Álvarez, X. & Picos, J. (2015) 'An assessment of river habitat quality as an indicator of conservation status. A case study in the Northwest of Spain', *Ecological Indicators,* 57, p131-138.

Wang, X. & Zhao, X. (2013) 'Ecological security sequential assessment of kunming based on fuzzy comprehensive evaluation method', *Yunnan Geographic Environment Research,* 25(5), p39-45.

Wang Xu, Marbowen, Li Dan, wait. (2020) 'Multi-scenario simulation and prediction of ecological space in Hubei province based on Flus Model' , *Journal of Natural Resources*, 2020,35(1), p230-242.

Ward, D.P., Murray, A.T. & Phinn, S.R. (2000) 'A stochastically constrained cellular model of urban growth', *Computers, Environment and Urban Systems,* 24(6), p539-558.

Wu, X., Liu, S., Sun, Y., An, Y., Dong, S. & Liu, G. (2019) 'Ecological security evaluation based on entropy matter-element model: A case study of Kunming city, southwest China', *Ecological Indicators,* 102, p469-478.

Xu, W., Ma, Z., Jing, X. & He, J. (2016) 'Biodiversity and ecosystem multifunctionality: advances and perspectives', *Biodiversity Science,* 24(1), p55-71.

Yohannes, H., Soromessa, T., Argaw, M. & Dewan, A. (2021) 'Spatio-temporal changes in habitat quality and linkage with landscape characteristics in the Beressa watershed, Blue Nile basin of Ethiopian highlands', *Journal of Environmental Management,* 281, p111885.

Yuan, F. (2008) 'Land-cover change and environmental impact analysis in the Greater Mankato area of Minnesota using remote sensing and GIS modelling', *International Journal of Remote Sensing,* 29(4), p1169-1184.

Zhang, Y., Liao, H. & Li, Y. (2019) 'Delimitation of urban growth boundary based on anti-planning and FLUS model: A case study of Yubei district, Chongqing', *Resources and Environment in the Yangtze Basin,* 28, p757-767.