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Simulation Prediction and Regulatory Zoning of Habitat Quality in Mountain City under the Spatiotemporal Evolution of Land Use

Bohang Zhang[1], Jianguo Wang[1], Yan Zhou[2]

[1]Faculty of Engineering and Information Technology, University of Technology Sydney, Sydney, Australia
[2]Department of Urban Planning, Hefei University of Technology, Hefei, China
Email: Bohang.Zhang@student.uts.edu.au

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Abstract

Mountain cities play a crucial role in maintaining global ecological security. Analyzing the spatiotemporal evolution characteristics of land use and habitat quality in these areas holds significant value and meaning for the sustainable development of the ecological environment. This study focuses on Xiuning County, a typical mountain city in China, utilizing land use data from 2000, 2010, and 2020. The PLUS model is employed to investigate land use expansion factors and conduct multi-scenario simulations for land use in 2030. Additionally, the InVEST model is applied to analyze the spatiotemporal evolution of habitat quality in Xiuning County and predict its condition under various scenarios in 2030. The findings reveal that the primary land use types in Xiuning County include forestland, cropland, construction land, grassland, and water bodies, with forestland occupying the largest area. Between 2000 and 2020, there was an increase in construction land, forestland, and grassland, while cropland and water bodies decreased. The predicted land use pattern for 2030 indicates overall stability, with forestland remaining the dominant type, although changes will occur in specific areas. From 2000 to 2020, the areas of low, relatively low, and medium habitat quality in Xiuning County decreased, whereas the areas of relatively high and high habitat quality increased, indicating an improvement in habitat quality over the past 20 years. The multi-scenario simulation predictions of habitat quality suggest that the ecological conservation model yields the highest quality, followed by the natural development model, with the urbanization development model presenting the lowest quality. Based on the habitat quality of each town, Xiuning County is classified into three regulatory zones: key development zones, flexible development zones, and optimized development zones. Targeted development recommendations are provided accordingly. The results of this study can serve as a scientific basis for ecological environment protection and urban development in Xiuning County and similar mountain cities.

Keywords

Mountain City, Habitat Quality, Spatiotemporal Evolution, Simulation Prediction, Regulatory Zoning

1. Introduction

Habitat quality is a key indicator for assessing biodiversity and ecosystem health (Jiang et al., 2024). It reflects an ecosystem's capacity to provide suitable living conditions for population development and serves as a resource carrier for organisms to perform normal life activities. Habitat quality plays a critical role in ensuring urban and regional ecological security and sustainable development (Zheng et al., 2022). The decline in habitat quality is a major environmental problem facing the world today (Mondal et al., 2024), threatening human well-being and sustainable development. Exploring ways to enhance habitat quality has become a research focus in the field of environmental management (Li et al., 2024). Land use is the foundation of habitat quality evaluation. However, with the rapid development of urbanization, the continuous expansion of urban construction land has led to drastic changes in land use patterns. This has resulted in the fragmentation of natural habitats and the degradation of ecosystem service functions, ultimately causing a decline or even deterioration of habitat quality. Therefore, evaluating the spatiotemporal characteristics and patterns of habitat quality based on land use changes holds significant value and importance for constructing urban and regional ecological security frameworks and promoting sustainable development.

Habitat quality assessment methods mainly include the indicator system evaluation method and the model evaluation method. The former evaluates habitat quality by selecting ecological impact factors but tends to overlook factors such as threat sources (Peng et al., 2021). The latter has been widely used in recent years, with commonly used models including the SoIVES model (Sherrouse et al., 2014), the InVEST model (Aneseyee et al., 2020), the MaxEnt model (Wang et al., 2021), and the HSI model (Collier et al., 2022), among which the InVEST model is the most widely used. Meanwhile, integrated studies that couple land use change with habitat quality evaluation have also been actively developed. Commonly used land use change models include the FLUS model (Lin et al., 2020), the CA-Markov model (Hishe et al., 2020), and the CLUE-S model (Kiziridis et al., 2023). The most recent is the PLUS model, which offers advantages in simulation accuracy and comprehensive multi-scenarios simulations (Han et al., 2024). Coupled models based on PLUS-InVEST have been widely applied in multi-scenario land use simulations, habitat quality assessments, spatiotemporal evolution and prediction of carbon storage, and other areas (Wu et al., 2024).

Mountain regions are complex ecosystems that play a crucial role in global ecological systems. UNESCO, through its Man and the Biosphere Programme (MAB), has designated critical keywords like mountains and cities as priority areas within the program (Huang, 2005). Mountain cities are defined as urban areas constructed on uneven slopes with gradients exceeding 5 degrees, which have different urban forms and habitat conditions compared to flatland cities (Zhang & Zhao, 2014). As the primary line of defense and strategic resource reserve for global ecological and environmental security, maintaining and enhancing the habitat quality of mountain cities holds significant strategic importance. This is a crucial fundamental prerequisite for the sustainable development of mountain cities. Currently, with the rapid progression of urbanization, mountain city ecosystems are facing increasing pressure. Unreasonable land use and vegetation destruction have accelerated land degradation and soil erosion, leading to ecosystem degradation, decreased resilience to disturbances, and weakened ecological service functions. Meanwhile, the inherent characteristics of mountain cities such as complex geographical environments, inconvenient transportation, homogeneous environmental structures, and imbalanced economic and social development have also exacerbated habitat degradation, further affecting the sustainable development of habitat quality in mountain cities. Therefore, in the face of the dual pressures of economic and social development and ecological environmental protection, studying the development and evolutionary patterns of habitat quality in mountain cities and predicting their future states are conducive to formulating policies and plans for territorial space development and conservation. This holds significant value and importance for the sustainable development of land use and the ecological environment in mountain cities.

Currently, research on the ecological environment of mountain cities primarily focuses on aspects such as species diversity (Zeng et al., 2022), climate comfort (Dong et al., 2024), impacts of natural disasters (Fischer et al., 2022), urban thermal environments (Chen et al., 2022), urban environment and quality of life (Dissanayake et al., 2020), and pollutant control(Cuesta-Mosquera et al., 2020). However, studies on habitat quality assessment and its simulation and prediction in mountain cities remain relatively scarce(Luan et al., 2022). Moreover, existing research mainly targets large-scale spatial areas (Li et al., 2023), and there is still a lack of studies on habitat quality in mountain cities at the county scale. Based on the above considerations, this study selects Xiuning County, a typical mountain city located in the southern mountains of Anhui Province, China as the research area. Utilizing land use data based on three periods from 2000 to 2020, we apply the InVEST-PLUS coupled model to analyze trends in land use and habitat quality changes, and to predict land use patterns and habitat quality for the year 2030. The aim is to provide a scientific decision-making basis for formulating ecological environmental policies and for the rational utilization of land resources, while also offering theoretical and methodological references for related research and practice in similar urban settings.

2. Study Area and Data

2.1. Overview of the Study Area

Xiuning County is located in the southernmost part of Anhui Province (Figure 1), adjacent to Huangshan City in Anhui and Jingdezhen City in Jiangxi Province. It administers 21 towns including Haiyang Town, Wan'an Town and Qiyunshan Town, covering a total area of approximately 212,610 hectares. The county's topography is predominantly mountainous, accounting for about 76.70% of its total area. The overall terrain is characterized by higher elevations in the north and south and lower elevations in the middle, featuring significant undulations and pronounced vertical height differences. The highest elevation within the county reaches approximately 1600 meters, while the lowest point is around 100 meters, resulting in a relative elevation difference of about 1500 meters. High mountain regions are mainly distributed in the southern and western parts of the county, while low mountains and hills are primarily located in the central and northern regions. Xiuning is a typical mountainous city described as having "eight parts mountain, half part water, half part farmland, and one part roads and villages."

Xiuning County is home to numerous mountain ranges, most notably Qiyun Mountain, a national key scenic spot which is located within its boundaries. As one of China's four major Taoist mountains, Qiyun Mountain contributes to Xiuning's status as a typical "mountain-city symbiosis" system, a feature that is distinctive and representative among county-level cities both nationally and globally. "Mountain-City Symbiosis" refers to a synergistic developmental relationship wherein the county's urban areas and the surrounding natural mountains are spatially intertwined, functionally interdependent, and ecologically integrated. This relationship manifests as a distinctive spatial pattern described as "the city nestled within the mountains, and the mountains embedded within the city." Within this system, the mountains serve as the ecological foundation, providing critical ecosystem services to the urban areas, while urban development simultaneously exerts a profound influence on the ecological health of the mountainous terrain. Together, these elements constitute an organic system characterized by the co-evolution of natural and human systems. Overall, as a typical representative of China's mountain cities, Xiuning County possesses outstanding geographical advantages, abundant mountain resources, and a favorable ecological environment. In recent years, the city's economy and society have developed rapidly; however, the urban ecological environment has consequently been subjected to the pressures and stresses of rapid economic and social development. Currently, many mountain cities in China, like Xiuning, are facing conflicts and contradictions between economic and social development and ecological environmental protection. Therefore, selecting Xiuning County as the research area is both typical and representative. The research findings are not only of great significance for the ecological environment protection of Xiuning County but also provide valuable references for ecological environment research in similar mountain cities.

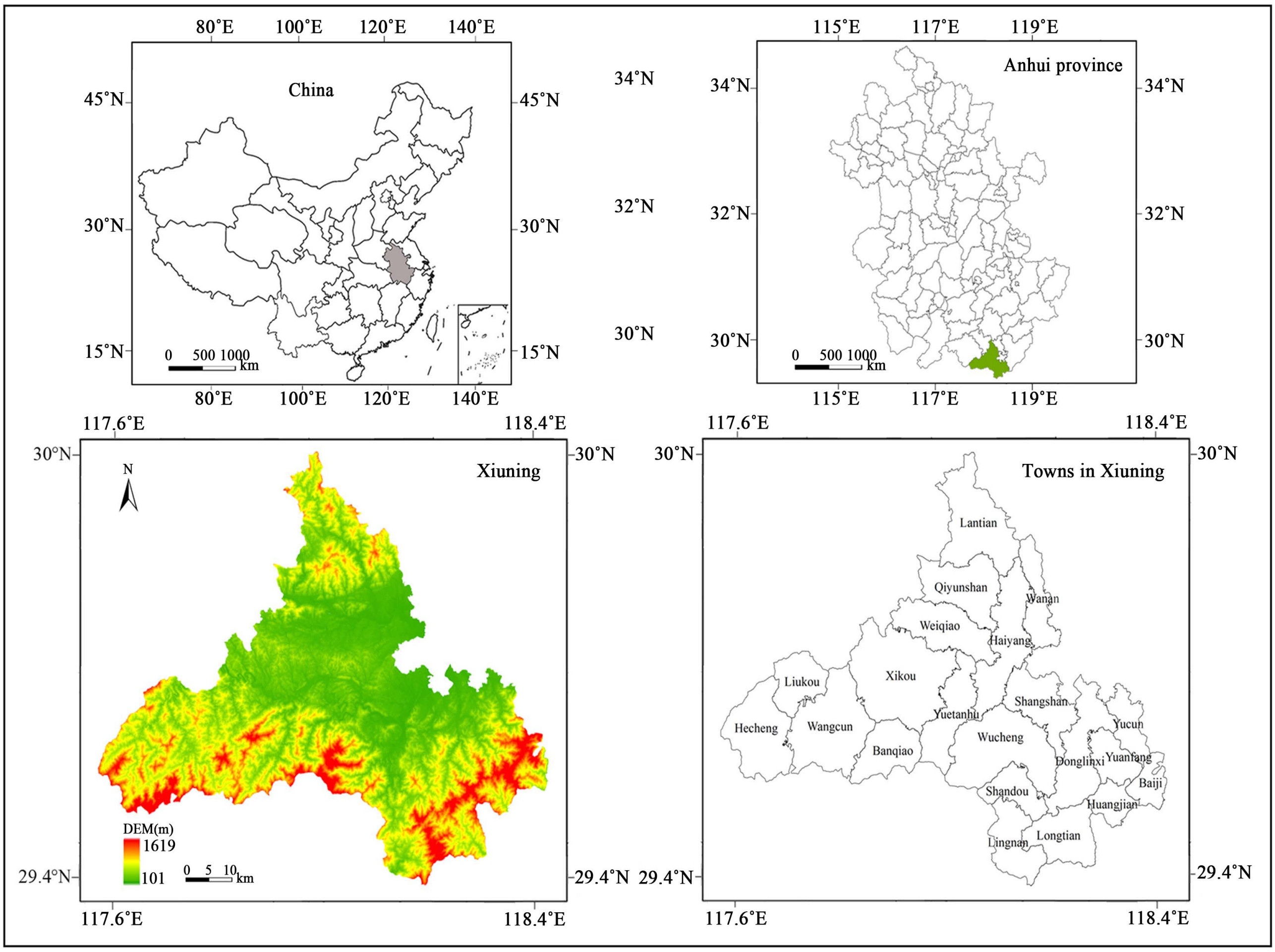

Figure 1. Location and extent of the study area.

2.2. Data Sources

The research data include administrative division data, land use data, natural environment data, socio-economic data and road traffic data. The sources of these various data types are presented in **Table 1**. Land use data were obtained for Xiuning County for the years 2000, 2010, and 2020, encompassing five major categories and 14 subcategories, such as cropland, forestland, grassland, water and construction land (**Table 2**). A total of 19 land use driving factors were selected from the natural environment data, socio-economic data and road traffic data. All data were processed using ArcGIS, standardized into raster data with a resolution of 30 m × 30 m, ensuring that they share the same number of rows and columns and the same coordinate system.

3. Methodology

3.1. InVEST Model

In the habitat quality module of the InVEST model, habitat quality is calculated

Table 1. Data information.

Type	Data Name	Source
Administrative division data	Administrative division data of Xiuning County	Data Center for Resources and Environmental Sciencesof the Chinese Academy of Sciences (https://www.resdc.cn)
Land use data	Land use data for Xiuning County	
Socio-economic data	X1 GDP	
	X2 Population	
	X3 Density of public service facilities	OpenStreetMap (https://www.openstreetmap.org)
Natural environment data	X4 DEM	Geospatial Data Cloud (http://www.gscloud.cn)
	X5 Slope	Perform operations on DEM data
	X6 Aspect	
	X7 Average annual precipitation	Data Center for Resources and Environmental Sciencesof the Chinese Academy of Sciences (https://www.resdc.cn)
	X8 Soil quality	
	X9 Average annual temperature	
Road traffic data	X10 Distance to urban main roads	OpenStreetMap (https://www.openstreetmap.org)
	X11 Distance to urban secondary roads	
	X12 Distance to urban branch roads	
	X13 Distance to highways	
	X14 Distance to Huangshan City	
	X15 Distance to Jingdezhen City	
	X16 Distance to railway	
	X17 Distance to railway stations	
	X18 Distance to town government	
	X19 Density of transportation facilities	

Table 2. Classification of land use in Xiuning.

First-Level Classification	Second-Level Classification
Cropland	Paddy field, Dry land
Forestland	Woodland, Shrubwood, Sparse forestland, Other forestlands
Grassland	High cover grassland, Moderate cover grassland
Water	River channel, Reservoirs and ponds, Tidal flat
Construction land	Urban land use, Rural settlement, Other construction land

based on land use types and the threat information they receive, fully considering factors such as the influence distances and spatial weights of stressors during computation. If a region exhibits high habitat quality, it indicates low fragmentation of land use patches, minimal threats, and strong resistance to disturbances. The habitat quality index serves as a comprehensive indicator for assessing the health status of a specific ecosystem or regional ecological environment, reflecting overall conditions and trends. The calculation formula is:

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

In the above formula, D_{xj} is the degree of habitat degradation for habitat type *j*, Q_{xj} is the habitat quality of habitat type *j*, H_j denotes the suitability of habitat type *j*, *k* is the half-saturation coefficient, and *z* is a normalization constant. The habitat quality index reflects the capacity of land use patches to resist disturbances resulting from ecological degradation under human activities. Its value ranges from 0 to 1, the closer the value is to 1, the better the habitat quality of the area, and the stronger the natural ecological effects exhibited by the land use patches, and vice versa. The calculation formula for D_{xj} is:

$$D_{xj} = \sum_{r=1}^{R}\sum_{y=1}^{Y_r}\left(\frac{W_r}{\sum_{r=1}^{R} W_r}\right) r_y i_{rxy} \beta_x S_{jr} \tag{2}$$

In the formula, *r* represents the threat factor, *R* is the number of threat factors, *y* is a set of raster cells of threat factor *r*, Y_r is the total number of raster for threat source *r*, W_r is the weight of the threat source, r_y is the stress value of raster *y*, i_{rxy} denotes the impact of raster *y* from threat source *r* on raster *x*, β_x is the accessibility of raster *x* to the threat factor, and S_{jr} is the sensitivity of land use type in the habitat type *j* to threat factor *r*. Based on the actual development situation in Xiuning County, cropland and construction land which are significantly affected by human disturbances are selected as threat factors. Various parameters are set with reference to existing studies (Zheng et al., 2024), as detailed in **Table 3**. Regarding the directness and persistence of threats, cropland and construction land exert continuous pressure on surrounding natural ecosystems (such as woodland, grassland, and water bodies) through frequent human activities. The spatial extent and intensity of this threat far exceed those of other potential but locally distributed threat factors. The spatial influence of specific road types (e.g., low-grade highways) or scattered industrial activities remains relatively limited, and their impacts are largely already reflected in the expansion of construction land. Therefore, selecting cropland and construction land as threat factors can objectively represent the actual conditions in Xiuning County. Additionally, habitat suitability and sensitivity to threat factors for different land use types are assigned values, as shown in **Table 4**. A higher value of habitat suitability indicates that the habitat tends toward naturalization, while lower values suggest a trend toward artificialization. Similarly, a higher sensitivity value of the habitat to threat factors means it is more sensitive and more vulnerable to threats; conversely, lower sensitivity values indicate that the habitat tends to be more stable.

3.2. PLUS Model

Existing land use modeling studies have primarily focused on improving technical modeling procedures, with less emphasis on understanding the underlying nonlinear relationships of land use and lacking the ability to predict land use changes

Table 3. Threat source and maximum impact distance.

Threat Sources	Distance of Maximum Impact (km)	Weight	Decay
Paddy field	1	0.5	Linear
Dry land	1	0.6	Linear
Urban land use	6	0.7	Exponential
Rural settlement	4	0.6	Exponential
Other construction land	8	0.8	Exponential

Table 4. Habitat suitability and sensitivity to threat factors of different land use types.

Land Use Type	Habitat Suitability	Paddy Field	Dry Land	Urban Land Use	Rural Settlement	Other Construction Land
Paddy field	0.40	0	0.1	0.55	0.55	0.5
Dry land	0.40	0.1	0	0.5	0.45	0.45
Woodland	1.00	0.55	0.35	0.8	0.75	0.75
Shrubwood	1.00	0.45	0.35	0.75	0.7	0.7
Sparse forestland	1.00	0.45	0.25	0.7	0.7	0.7
Other forestlands	1.00	0.45	0.25	0.7	0.7	0.65
High cover grassland	0.80	0.4	0.2	0.65	0.65	0.6
Moderate cover grassland	0.70	0.35	0.2	0.6	0.6	0.6
River channel	0.40	0.75	0.15	0.85	0.75	0.7
Reservoirs and ponds	0.30	0.75	0.15	0.8	0.75	0.7
Tidal flat	0.60	0.85	0.45	0.82	0.8	0.75
Urban land use	0	0	0	0	0	0
Rural settlement	0	0	0	0	0	0
Other construction land	0	0	0	0	0	0

at the patch scale. Recently, the newly proposed Patch-generating Land Use Simulation (PLUS) model has enabled the prediction of land use changes at the patch scale based on raster data. It introduces a rule-mining framework based on the Land Expansion Analysis Strategy (LEAS) and a Cellular Automata model based on multi-type random seeds (CARS), which can extract the driving factors of land expansion and landscape changes, thereby achieving higher simulation accuracy and more realistic landscape evolution (Sun et al., 2023). The LEAS calculates the development probability of each land type using the Random Forest algorithm based on two periods of land use data and computes the contribution rates of selected land expansion driving factors. The calculation formula is as follows:

$$P_{i,k(x)}^{d} = \frac{\sum_{n=1}^{M} I\left(h_n(x) = d\right)}{M} \quad (3)$$

In the formula, x is the vector of driving factors; $P_{i,k}^{d}(x)$ is the probability of expansion of land use type k within patch i under $d = 0$ or $d = 1$, where $d = 1$

indicates the conversion of other land types to land type k, and $d = 0$ indicates land use conversions that do not include land type k. M is the number of decision trees, $I()$ is the decision tree indicator function, and $h_n(x)$ represents the land use type obtained when the decision tree is n. Under the constraints of the development probabilities of various land use types, the model generates land use patches based on CARS and a threshold decrement mechanism. The calculation formula as:

$$OP_{i,k}^{d=1,t} = P_{i,k}^{d} \times \Omega_{i,k}^{t} \times D_{k}^{t} \quad (4)$$

where, $OP_{i,k}^{d=1,t}$ is the comprehensive probability that patch i transitioning to land use type k at time t, $P_{i,k}^{d}$ is the suitability probability of patch i transitioning to land use type k, $\Omega_{i,k}^{t}$ is the coverage proportion of land use type k in the neighborhood, and D_{k}^{t} is the impact of future demand on land use type k.

Model accuracy is the key to determine whether the model can be applied in practice. This study employs the Kappa coefficient to validate the model accuracy; higher values indicate greater precision (Cicchetti & Feinstein, 1990). Typically, a Kappa coefficient exceeding 0.75 signifies that the model accuracy meets statistical requirements (Chen et al., 2019), making it suitable for future predictive applications. Conversely, if the model accuracy does not meet the required standards, it is necessary to revisit and adjust various parameters within the coupled model, followed by re-simulation until the desired accuracy is achieved. Additionally, the Figure of Merit (FoM) can also be used for evaluation (He et al., 2018), as it measures the consistency between actual changes and simulated changes. When the area of land use change in the study region is small, the traditional significance of the Kappa coefficient diminishes, and the FoM can serve as an auxiliary test in such cases.

Based on the land use data of Xiuning County for the years 2000 and 2010, and selecting 19 influencing factors such as elevation, population, and GDP, we applied the PLUS model to predict the land use patterns for 2020. By comparing the predicted results with the actual 2020 land use data, we obtained a Kappa coefficient of 0.91 and a FoM value of 0.17, indicating that the simulation results are highly accurate. Therefore, the model can be utilized to predict the land use patterns of Xiuning County for 2030.

3.3. Future Development Scenario Setting

The study establishes three development scenarios, namely the natural development model (NDM), the urbanization development model (UDM), and the ecological conservation model (ECM), to predict changes in land use and habitat quality in Xiuning County by 2030. These scenarios are based on the actual land use conditions of the research area and reference relevant policies of the Xiuning County government concerning spatial land planning, ecological environment protection, and construction.

The NDM serves as the most fundamental simulation scenario, allowing for mutual conversions among all land use types without considering the influence of policy factors and without setting restricted development areas. The UDM represents a proactive spatial development scenario centered on socio-economic growth. In this mode, the probability of converting construction land to other land use types is reduced, the conversion of construction land to other categories is restricted, and the probability of converting non-construction land to construction land is moderately increased. This approach aims to maximize the acquisition of construction land. The ECM prioritizes the preservation of the natural ecological environment. In this scenario, forestland, cropland, grassland, and water are strictly protected, limiting their conversion to construction land. Additionally, the probability of converting construction land back to forestland is moderately increased. Important water areas are designated as restricted development zones, within which land use conversions are prohibited. This strategy is designed to maximize the protection of habitat quality.

4. Results

4.1. Land Use Analysis

4.1.1. Land Use Change

The land use status and changes in Xiuning County from 2000 to 2020 are presented in Figure 2 and Table 5. Figure 2 illustrates that forestland is the most extensively distributed land use type in Xiuning County, serving as the primary land cover with strip-like and patchy distributions of cropland, grassland, construction land, and water area embedded within. During the past 20 years, construction land in Xiuning County has continuously expanded spatially, particularly in the central urban area and several central towns, resulting in the formation of several distinct construction land concentration zones. Cropland is predominantly distributed in the northern, central, and eastern regions of the county, forming several clear belt-like areas, while in other regions it exhibits a scattered patchy distribution pattern. Grassland is dispersed throughout the county, primarily existing as small patches interspersed among various land use types. Water areas are mainly concentrated in the northern river areas of the county, and their area has remained generally stable over the 20 years, with minimal changes observed.

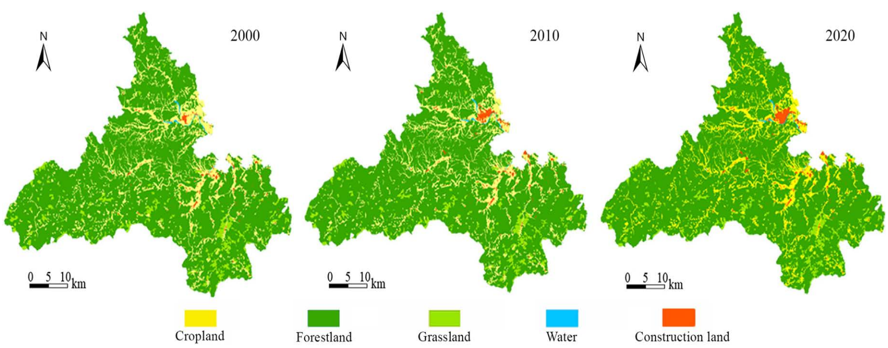

Figure 2. Distribution map of land use type in Xiuning from 2000 to 2020.

According to Table 5, from 2000 to 2020, the land use pattern in Xiuning County, which is predominantly forested, remained generally stable overall. However, localized changes were observed, primarily characterized by a rapid increase in construction land and a significant decrease in cropland. Additionally, there was a noticeable expansion in forestland area, a slight increase in grassland area, and a marginal decline in water area. Specifically, the cropland area decreased from 31865.57 hectares in 2000 to 29812.73 hectares in 2020, resulting in a reduction of 2052.84 hectares, which is the largest decrease among all land use types. The area of water decreased by a total of 1.55 hectares over the 20-year period, remaining essentially stable. During the 20-year period, the areas of construction land, forestland and grassland increased by 1429.07 hectares, 592.12 hectares, and 33.20 hectares, respectively, with construction land exhibiting the most significant growth.

Table 5. Area changes of each land use type in Xiuning from 2000 to 2020 (hectare).

Land Use Type	2000	2010	2020	Area Changes		
				2000~2010	2010~2020	2000~2020
Cropland	31865.57	30202.18	29812.73	−1663.39	−389.45	−2052.84
Forestland	168126.26	168807.41	168718.38	681.15	−89.03	592.12
Grassland	10672.30	10684.07	10705.50	11.77	21.43	33.20
Water	415.36	413.81	413.81	−1.55	0.00	−1.55
Construction land	1530.52	2502.54	2959.59	972.02	457.05	1429.07

Based on land use data from 2000 to 2020, the land use transfer matrix for Xiuning County (Table 6) and the transfer Sankey diagram (Figure 3) were constructed. The results indicate that from 2000 to 2010, there were significant transfers among construction land, forestland and cropland. Specifically, 844.15 hectares of cropland and 158.30 hectares of forestland were converted to construction land. Additionally, 1473.31 hectares of cropland and 147.88 hectares of grassland were transformed into forestland. Concurrently, due to the implementation of the most stringent cropland protection measures by the Chinese government in recent years, 634.88 hectares of forestland, 13.33 hectares of water, and 24.33 hectares of construction land were converted back to cropland. However, the area of cropland loss exceeded the area gained. From 2010 to 2020, the land use transitions exhibited similar overall characteristics to the preceding decade, with ongoing exchanges among construction land, forestland, and cropland remaining the primary drivers of land use change in Xiuning County. However, Figure 3 illustrates that the total area of land transfers during this period (2080.78 hectares) was significantly smaller than that of the previous decade (3497.47 hectares), indicating a marked reduction in the intensity of land use transitions. Overall, between 2000 and 2020, the largest area of land conversion was the loss of cropland, totaling 3006.91 hectares, followed by forestland and grassland, with 1319.03 hectares and 220.33 hectares lost, respectively. In terms of land gains, forestland saw the highest increase with 1911.12 hectares, followed by construction land and cropland, which increased by 1472.22 hectares and 954.31 hectares, respectively. In summary, over the 20-year period, the primary types of land use transitions in Xiuning County were among cropland, construction land, and forestland.

Table 6. Land use transfer matrix in Xiuning from 2000 to 2020 (hectare).

Time	Land Use Type	Grassland	Cropland	Construction Land	Forestland	Water
2000~2010	Grassland	10510.04	13.33	0.63	147.88	—
	Cropland	17.86	29522.91	844.15	1473.31	6.60
	Construction land	0.54	24.33	1498.07	7.34	0.28
	Forestland	155.54	634.88	158.30	167173.11	2.09
	Water	—	6.11	0.94	3.36	404.89
2010~2020	Grassland	10526.28	13.53	0.37	142.30	—
	Cropland	15.33	29153.36	465.55	561.25	5.81
	Construction land	0.28	33.06	2448.51	19.88	0.73
	Forestland	162.11	608.08	43.50	167989.45	1.17
	Water	—	3.91	1.43	2.49	405.93
2000~2020	Grassland	10449.93	19.39	0.77	200.17	—
	Cropland	26.16	28857.28	1278.65	1694.49	7.61
	Construction land	0.54	30.99	1486.73	11.81	0.46
	Forestland	227.29	898.35	191.24	166802.65	2.15
	Water	—	5.58	1.56	4.65	403.73

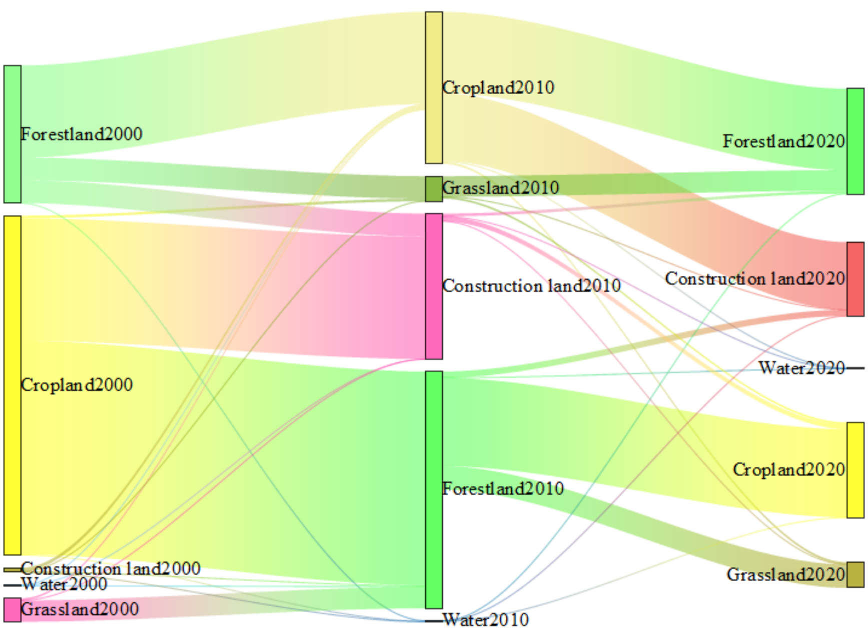

Figure 3. A Sankey graphic illustrating the land use transfer in Xiuning from 2000 to 2020.

4.1.2. Analysis of Land Use Expansion

The land use data for Xiuning County from 2000 and 2020 were input into the PLUS model. Utilizing the LEAS module and the Random Forest algorithm, development potential maps for each land use type and the contribution values of various driving factors to the expansion of each land use type were generated. The results are presented in Figure 4 and Figure 5. Among the driving factors for cropland expansion, the distance to railway stations, distance to highways, average annual temperature, and elevation are the four most influential factors. Areas with high development potential are primarily concentrated in the northern, central, and eastern regions of the county, exhibiting dense clump-like and patchy distribution patterns. Forestland expansion is primarily influenced by driving factors such as distance to highways, distance to railway stations, and average annual precipitation. High development potential areas for forestland are distinctly concentrated in the western region of the county, forming a prominent and extensive contiguous zone. In contrast, other regions exhibit smaller, scattered high-potential areas for forestland development. Grassland expansion is primarily influenced by average annual precipitation and average annual temperature. Areas with high development potential for grasslands are mainly concentrated in the western, southern, and eastern border regions of the county, exhibiting a distinct strip-like distribution pattern. Water areas are mainly affected by average annual temperature, with high development potential areas displaying a scattered, point-like distribution pattern.

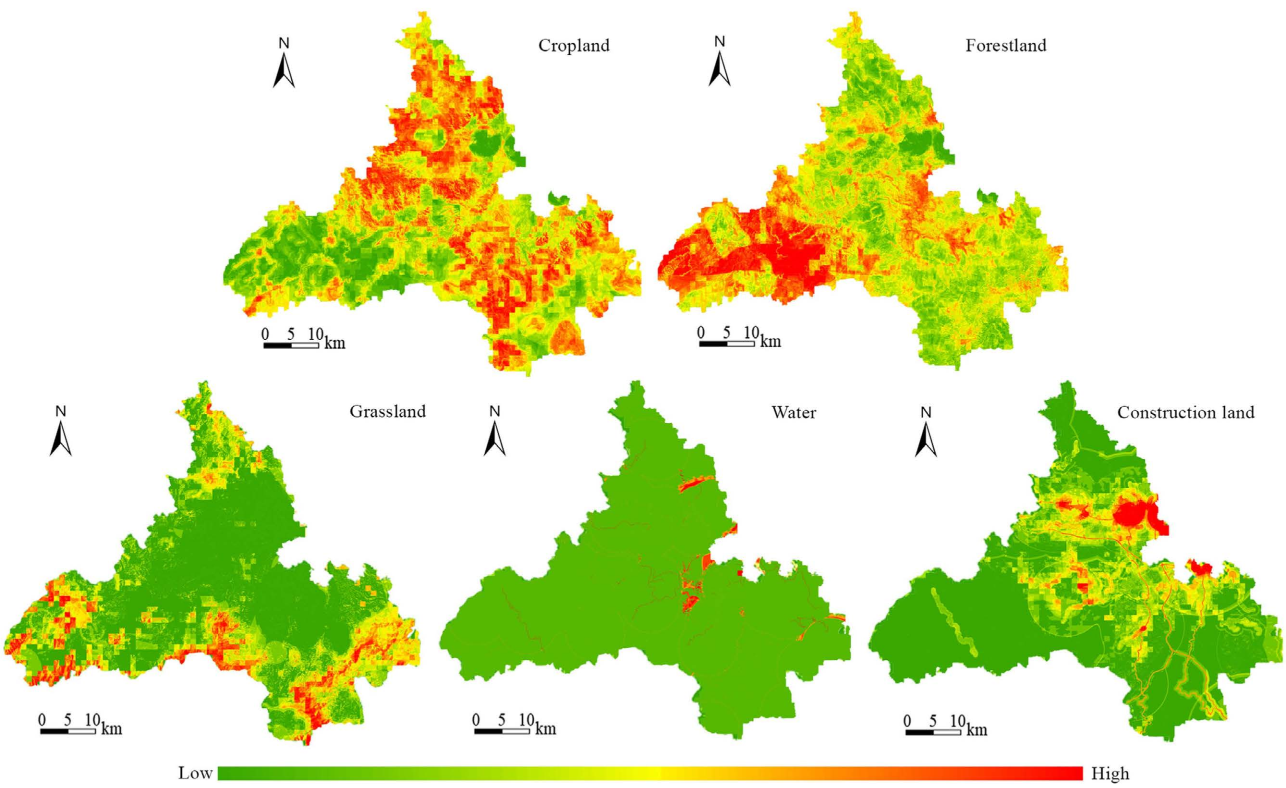

Figure 4. Development potential map of land use types in Xiuning.

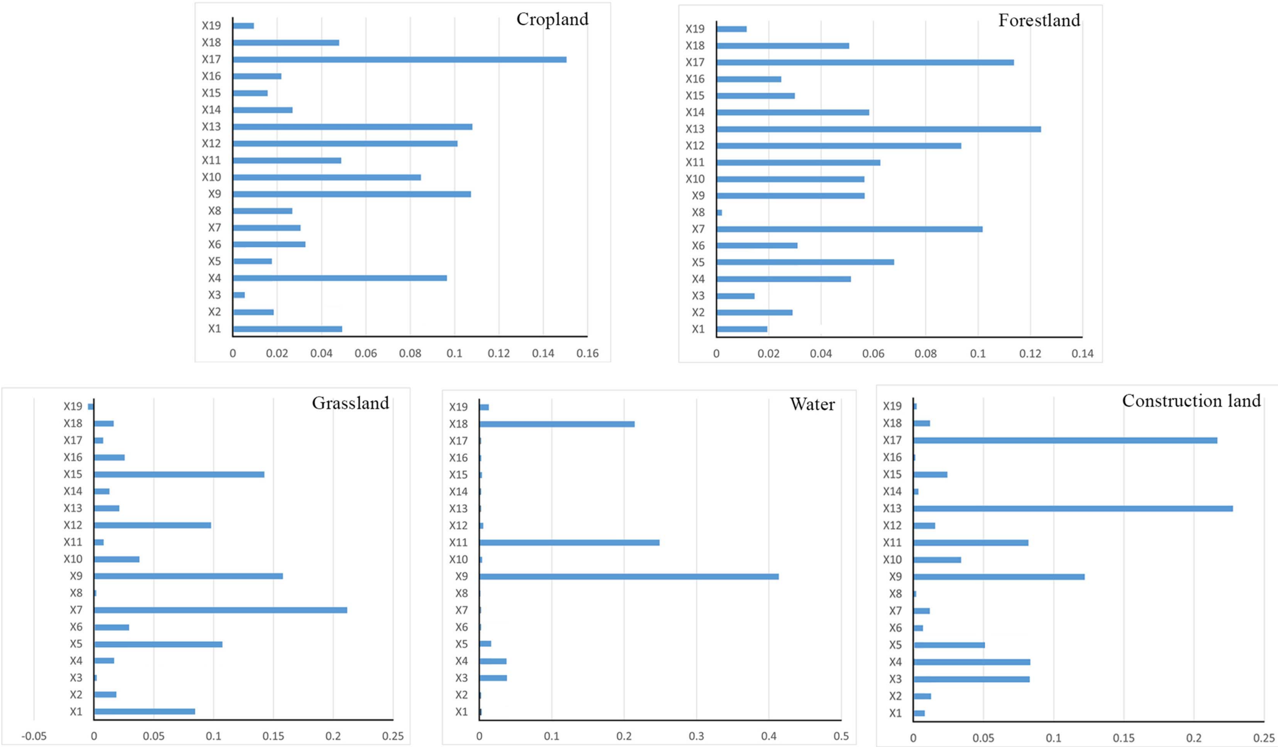

Figure 5. Contribution degree of land use driving factors in Xiuning from 2000 to 2020.

Among the driving factors for construction land expansion, distance to highways has the highest contribution, followed by distance to railway stations and average annual temperature. This indicates that the expansion of construction land in Xiuning County is closely related to transportation conditions—the more convenient the transportation, the greater the extent of construction land expansion. The central urban area has the highest transportation network density and exhibits the most pronounced construction land expansion. Additionally, the administrative centers of various towns in the central and eastern regions possess relatively favorable transportation conditions, resulting in higher potential for construction land expansion compared to other areas. Spatially, high-potential areas for construction land are primarily centered around the central urban area, which serves as the largest core zone. Expansion radiates outward along major transportation corridors from this core. Simultaneously, several smaller high-potential zones have formed in the central and eastern regions of the county, each also expanding outward from their respective cores.

Overall, among the driving factors for cropland, forestland and construction land, transportation-related factors exhibit the highest contributions, followed by natural environmental factors, while socio-economic factors contribute relatively less. In contrast, grassland and water are more significantly influenced by natural environmental factors. This indicates that, as a typical mountain city, road transportation is the predominant driving factor influencing land use changes in Xiuning County. Efficient road transportation conditions can effectively mitigate the barriers posed by the mountainous topography, thereby facilitating various development and construction activities as well as socio-economic interactions and exchanges. Consequently, this promotes the expansion and transformation of different land use types. In the case of Xiuning County, the constraints imposed by the mountainous natural terrain are the primary factor governing development. This compels spatial land-use patterns to preferentially follow paths of least topographical resistance—namely, expansion along major transportation corridors—rather than fully responding to economic demands. Consequently, transportation and topography supersede abstract economic drivers, shaping an expansion mode dominated by transport and natural factors.

4.2. Spatiotemporal Evolution of Habitat Quality

4.2.1. Changes in Habitat Quality Levels

Based on the three periods of land use data for Xiuning County, the InVEST model was employed to calculate the habitat quality of Xiuning County from 2000 to 2020. Utilizing the natural break classification method, the habitat quality was categorized into five distinct levels: low, relatively low, medium, relatively high and high. Additionally, the proportion of each habitat quality level and the transitions between these levels were quantified and analyzed. Table 7 illustrates that from 2000 to 2020, the area of low habitat quality in Xiuning County consistently decreased, reducing to 21815.54 hectares by 2020. This represents a cumulative reduction of 3579.45 hectares and a 1.68% decrease in area proportion compared to 2000. The areas of relatively low and medium habitat quality initially declined and subsequently increased; however, by 2020, they were still 624.10 hectares and 281.66 hectares less than in 2000, respectively. In contrast, the areas of relatively high and high habitat quality first expanded and then contracted, yet by 2020, they had still increased by 2254.59 hectares and 2230.62 hectares compared to 2000, respectively. Overall, over the 20-year period, the areas of low, relatively low, and medium habitat quality in Xiuning County decreased, while the areas of relatively high and high habitat quality increased. These trends indicate a continuous improvement in the ecological environmental quality of Xiuning County.

Table 7. Area (hectare) and proportion (%) of different habitat quality levels in Xiuning from 2000 to 2020.

Habitat Quality Level	2000		2010		2020	
	Area	Proportion	Area	Proportion	Area	Proportion
Low	25394.99	11.94	22690.28	10.67	21815.54	10.26
Relatively low	13425.02	6.31	12041.8	5.66	12800.92	6.02
Medium	50714.31	23.85	49884.97	23.46	50432.65	23.72
Relatively high	59516.77	27.99	62000.14	29.16	61771.36	29.05
High	63558.91	29.91	65992.81	31.05	65789.53	30.95

4.2.2. Spatial Distribution of Habitat Quality Levels

Figure 6 indicates that the spatial distribution of habitat quality in Xiuning

County exhibits significant variability. High habitat quality areas (relatively high and high) are the most extensively distributed, primarily concentrated in the forest and grassland regions of the western, northern, and southeastern parts of the county. Conversely, low habitat quality areas (low and relatively low) are mainly concentrated in the construction land of the eastern county. Medium habitat quality areas are situated in the transitional areas between high and low habitat quality regions. From 2000 to 2010, high habitat quality areas in the southwestern, northern, and southeastern regions of Xiuning County exhibited localized increases. Concurrently, low habitat quality areas in the central and eastern regions experienced localized decreases, and medium habitat quality areas also showed localized reductions. Between 2010 and 2020, high habitat quality areas remained largely stable, whereas low and medium habitat quality areas underwent localized expansions. However, these changes continued to align with the distribution of construction land and maintained a general state of stability. High habitat quality areas are located away from urban development and construction zones, exhibiting concentrated and contiguous spatial distribution patterns. In contrast, low habitat quality areas are primarily composed of construction land and cropland, displaying radial and strip-like spatial characteristics with a tendency to expand outward. Meanwhile, medium habitat quality areas are scattered distributed across the landscape. Overall, the spatial distribution of habitat quality in Xiuning County exhibits a pronounced "high peripheral, low central" pattern. Additionally, a distinctive feature is the presence of two major concentration cores represented by high habitat quality areas in the western forests and low habitat quality areas in the central urban area, forming Xiuning County's unique "mountain-city" dual-core spatial structure. This characteristic aligns inherently with Xiuning County's identity as a prominently featured mountain city. The western forests serve as the largest and most important ecological protection source in Xiuning County, while the central urban area constitutes the county's largest aggregation zone for construction land. The necessity to protect the ecological environment juxtaposed with the imperative for urban development and construction highlights the conflicts and contradictions between development and conservation. These dynamics underscore the opportunities and challenges faced by Xiuning's "mountain-city symbiosis" ecological system.

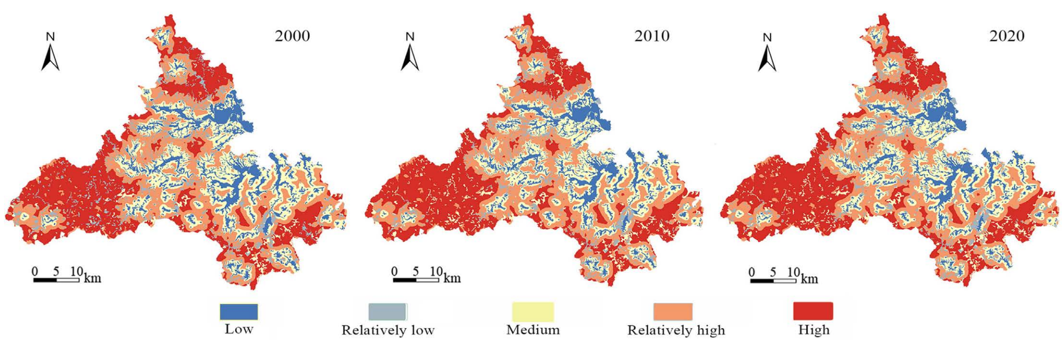

Figure 6. Habitat quality distribution in Xiuning from 2000 to 2020.

4.2.3. Habitat Quality Level Transfer

Table 8 illustrates that from 2000 to 2010, the outflow from medium habitat quality areas in Xiuning County was the highest, totaling 5853.23 hectares, whereas the outflow from high habitat quality areas was the lowest, amounting to 1189.64 hectares. Conversely, the inflow into relatively high habitat quality areas was the greatest, with an increase of 6575.36 hectares, while the inflow into low habitat quality areas was the smallest, totaling 689.82 hectares. From 2010 to 2020, the outflow from low habitat quality areas in Xiuning County became the highest, totaling 1293.57 hectares, whereas the outflow from high habitat quality areas remained the lowest, amounting to 452.44 hectares. During this period, the inflow into relatively low habitat quality areas was the most significant, increasing by 1319.57 hectares, while the inflow into high habitat quality areas was the least, with an increase of 249.23 hectares. Figure 7 demonstrates that the total area of land undergoing habitat quality level transitions from 2010 to 2020 (3934.91 hectares) was markedly smaller than that of the preceding decade (19141.27 hectares), indicating a significant reduction in the intensity of habitat quality transitions during this period.

Table 8. Habitat quality level transfer matrix in Xiuning from 2010 to 2020/(hectare).

Habitat Quality Level		2010					
		Low	Relatively low	Medium	Relatively high	High	Total of outflow
2000	Low	-	2838.36	413.78	136.03	6.48	3394.65
	Relatively low	208.83	-	3320.46	245.42	837.00	4611.71
	Medium	459.02	145.28	-	5180.95	67.98	5853.23
	Relatively high	21.97	215.00	1144.55	-	2710.52	4092.04
	High	-	29.65	147.03	1012.96	-	1189.64
	Total of inflow	689.82	3228.29	5025.82	6575.36	3621.98	-
Habitat Quality Level		2020					
		Low	Relatively low	Medium	Relatively high	High	Total of outflow
2010	Low	-	957.97	335.13	0.47	-	1293.57
	Relatively low	93.01	-	260.97	185.50	20.99	560.47
	Medium	325.09	136.76	-	174.26	120.95	757.06
	Relatively high	0.59	203.03	560.46	-	107.29	871.37
	High	-	21.81	148.50	282.13	-	452.44
	Total of inflow	418.69	1319.57	1305.06	642.36	249.23	-
Habitat Quality Level		2020					
		Low	Relatively low	Medium	Relatively high	High	Total of outflow
2000	Low	-	3684.74	543.07	136.96	6.43	4371.20
	Relatively low	196.46	-	3461.95	305.79	863.99	4828.19

Continued

Medium	569.07	195.32	-	4995.71	88.00	5848.10
Relatively high	25.79	286.83	1348.99	-	2639.81	4301.42
High	-	37.42	214.43	1117.32	-	1369.17
Total of inflow	791.32	4204.31	5568.44	6555.78	3598.23	-

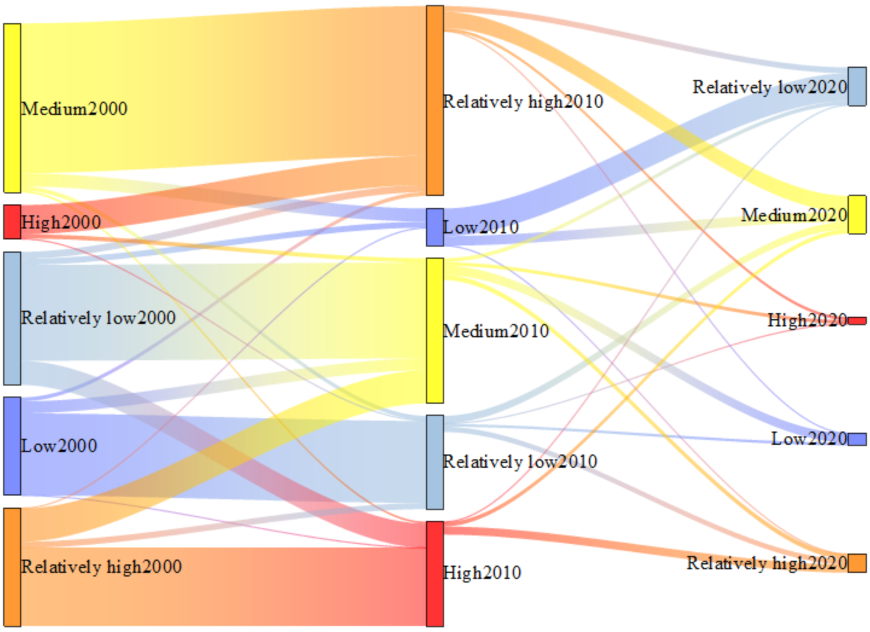

Figure 7. A Sankey graphic illustrating the habitat quality level transfer in Xiuning from 2000 to 2020.

According to **Table 8** and **Figure 8**, from 2000 to 2020, the outflow from medium habitat quality areas in Xiuning County was the highest, totaling 5848.10 hectares, whereas the outflow from high habitat quality areas was the lowest, amounting to 1369.17 hectares. Conversely, the inflow into relatively high habitat quality areas was the greatest, increasing by 6555.78 hectares, while the inflow into low habitat quality areas was the smallest, with an increase of 791.32 hectares. Overall, over the 20-year period, the primary types of habitat quality improvement in Xiuning County involved transitions from low to relatively low, relatively low to medium, medium to relatively high, and relatively high to high habitat quality, with respective transfers of 3684.74 hectares, 3461.95 hectares, 4995.71 hectares, and 2639.81 hectares. These improvements collectively accounted for an increase of 14782.21 hectares, representing 6.95% of Xiuning County's total area. In contrast, habitat quality degradation primarily consisted of transitions from medium to low, relatively high to medium, and high to relatively high habitat quality, with respective transfers of 569.07 hectares, 1348.99 hectares, and 1117.32 hectares, totaling 3035.38 hectares and accounting for 1.43% of the county's total area. Comparatively, the area undergoing habitat quality improvement significantly exceeds that of habitat quality degradation. This disparity further demonstrates that the overall habitat quality in Xiuning County has improved over the two-decade period.

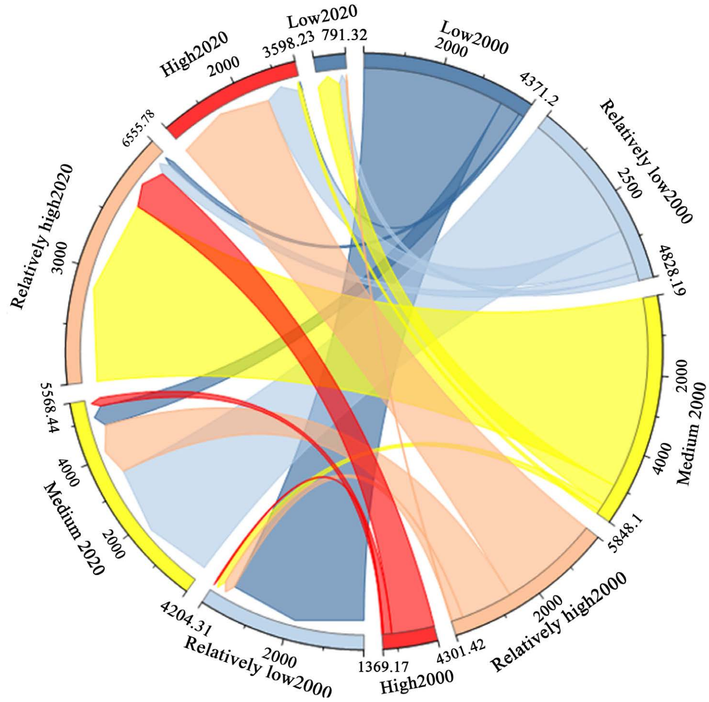

Figure 8. A chord graphic illustrating the habitat quality level transfer in Xiuning from 2000 to 2020.

4.2.4. Spatial Distribution of Habitat Quality Level Transfer

Figure 9 illustrates the spatial distribution of dynamic habitat quality changes in Xiuning County from 2000 to 2020. During the 2000-2010 period, multiple patches in towns such as Haiyang, Weiqiao, Banqiao, Yuanfang, and Yucun transitioned from higher to lower habitat quality levels, resulting in the formation of several distinct aggregation zones. In the 2010-2020 period, the spatial distribution of habitat quality transitions exhibited a "centralized core with surrounding dispersion" pattern, with high-quality habitat patches transitioning to lower quality primarily concentrated in Yuetan Lake and Weiqiao towns. Over the entire 2000-2020 period, towns including Haiyang, Weiqiao, Banqiao, Yuanfang, Baiji, and Yucun experienced multiple patches transitioning from higher to lower habitat quality levels, thereby forming several prominent aggregation zones. Additionally, other towns displayed a greater number of patches transitioning from medium to either higher or lower habitat quality levels.In the spatiotemporal transitions of habitat quality in Xiuning County, an overall trend of "localized abundance with overall moderation" is observed. From 2000 to 2010, localized changes in habitat quality transitions were relatively prominent, indicating significant alterations in land use in specific areas, while the overall average level of habitat quality transitions remained relatively stable. However, from 2010 to 2020, the trend of habitat quality transitions underwent notable changes. Compared to the preceding decade, habitat quality transitions during this period exhibited a more homogeneous pattern, with overall differences being minimal and localized changes less apparent. This suggests that over the past ten years, the habitat quality in Xiuning County has tended toward stability, with relatively fewer changes in land use types and more consistent maintenance of habitat quality.

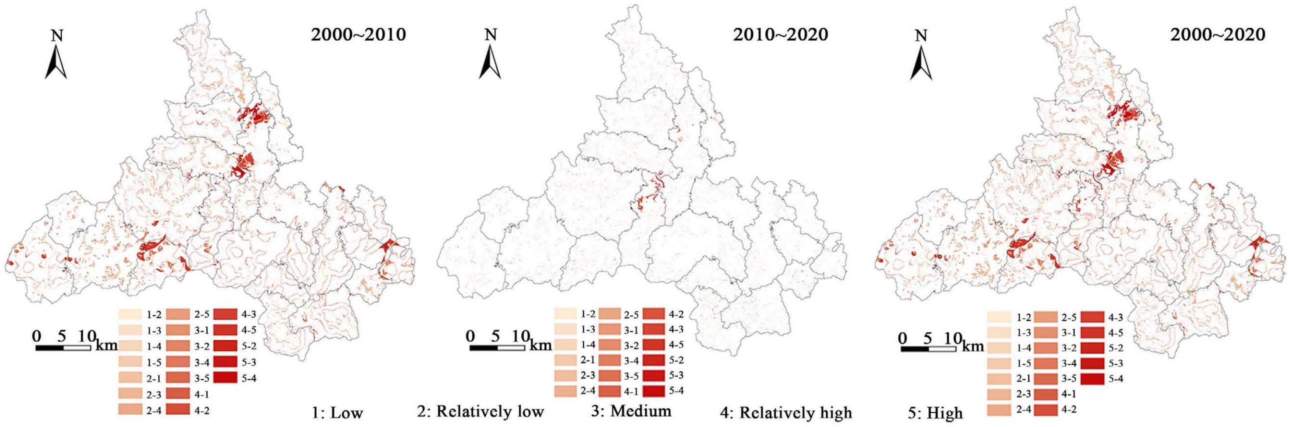

Figure 9. Spatial distribution of dynamic transfer of habitat quality in Xiuning from 2000 to 2020.

4.3. Simulation and Prediction of Land Use Change

Based on the land use patterns and the spatiotemporal evolution characteristics of habitat quality in Xiuning County, and according to the development scenarios of the NDM, UDM, and ECM, different calculation parameters were set in the PLUS model for each development scenario. This enabled the simulation and prediction of land use data in Xiuning County under the three development scenarios for the year 2030, as illustrated in Figure 10.

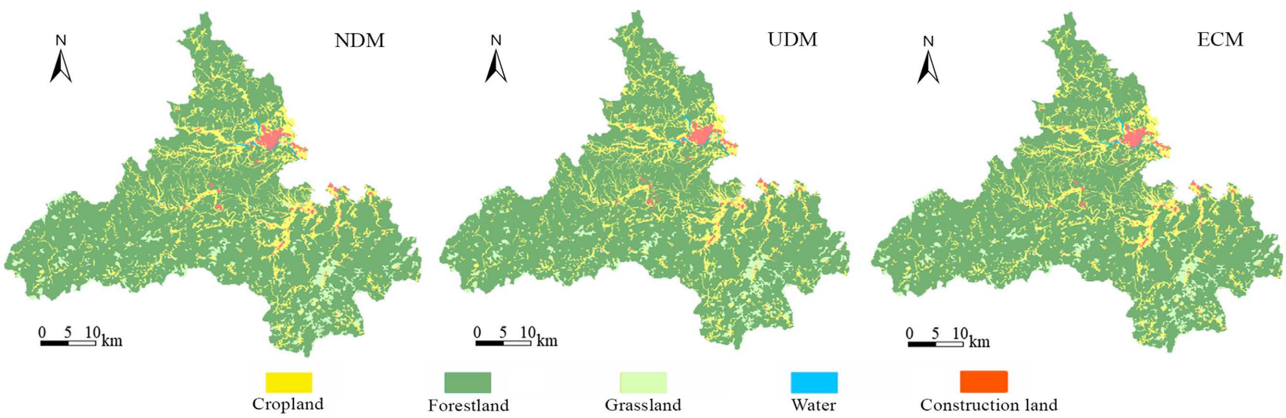

Figure 10. Prediction of land use types in Xiuning in 2030.

According to Figure 10, under the NDM, the areas of construction land in towns such as Haiyang, Wan'an, and Xikou expand rapidly, encroaching significantly on cropland and forestland. Specifically, cropland in Haiyang and Wan'an towns decreases substantially, while spatial changes in grassland in the southern part of the county remain insignificant. Under the UDM, Haiyang and Wan'an towns, which possess better construction infrastructure and higher construction density, exhibit pronounced expansion of construction land. Construction land in Xikou town expands with high density in certain areas, and in Yucun and Wucheng towns, construction land shows localized small-scale expansion. Concurrently, forestland areas contract; however, forestland continues to be the dominant land use type. Under the ECM, the trend of construction land expansion either slows down or halts entirely, while forestland areas experience some expansion. Overall, forestland remains the dominant land use type in Xiuning County's land use projections for 2030. Terrestrial water bodies continue to be limited, grassland changes are minimal, and the aggregation patterns of cropland and construction land resemble those observed in 2020, albeit with some variations in specific localized areas. Notably, the UDM results in the largest quantity of construction land, the ECM yields the highest number of ecological land types, and the NDM continues the past state of development.

4.4. Simulation and Prediction of Habitat Quality

Based on the simulated land use data for 2030 under the three development scenarios in Xiuning County, the InVEST model was utilized to simulate habitat quality (**Figure 11**) and calculate the area changes of each habitat quality level (**Table 9**). The results indicate that under the NDM, the area of high habitat quality is the largest, totaling 63731.84 hectares, which accounts for 29.97%. This is followed by the areas of relatively high and medium habitat quality, which represent 27.30% and 24.33%, respectively. The areas of low and relatively low habitat quality are significantly smaller, at 11.65% and 6.75%. In terms of spatial distribution, high habitat quality areas are primarily concentrated in the mountainous regions of the northern, southwestern, and southeastern parts of the county, forming a cohesive spatial pattern. Low habitat quality areas are mainly located in the eastern and central regions, which are the primary zones of construction land aggregation. Medium habitat quality areas are found in transitional zones between high and low quality regions. Overall, under the NDM, there is no significant large-scale expansion of construction land and low habitat quality areas. The habitat quality in the county remains in a favorable development state, aligning well with the existing patterns of land use.

According to **Table 9**, compared to the NDM, the area of high habitat quality significantly decreased under the UDM, with a reduction of 1.07% in proportion. In contrast, the area of medium habitat quality increased significantly, with a proportional increase of 1.95%, while the areas of other habitat quality levels remained largely unchanged. Spatially, high value areas contracted, primarily in the transitional zones between high and low value regions, where more high value areas were downgraded to medium value. The aggregation effect of constructed land intensified, with low habitat quality areas in the central and eastern regions expanding to some extent, leading to an overall decline in habitat quality compared

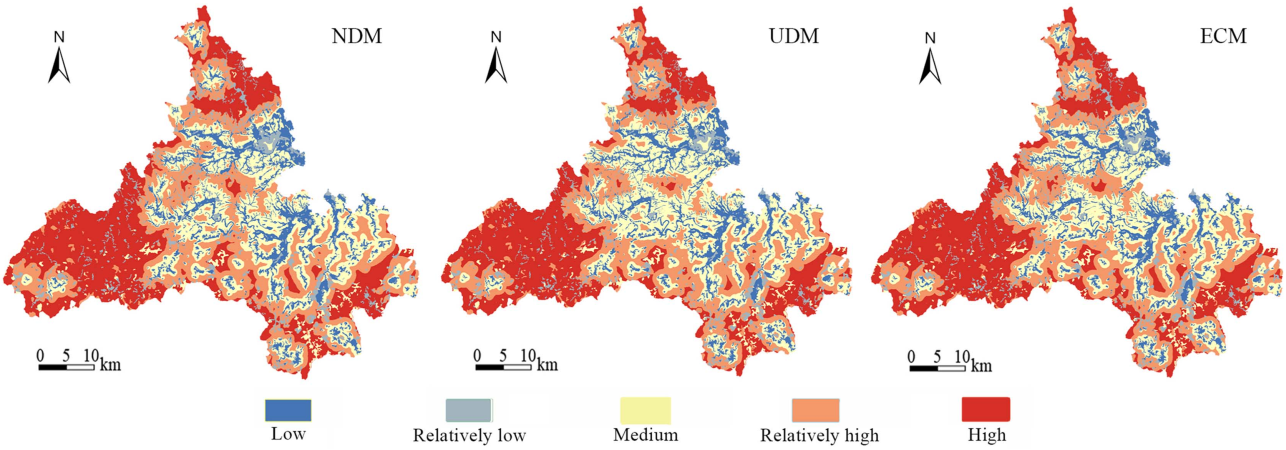

Figure 11. Habitat quality prediction in Xiuning in 2030.

Table 9. Area (hectare) and proportion (%) of different habitat quality levels in Xiuning in 2030.

Habitat Quality Level	NDM		UDM		ECM	
	Area	Proportion	Area	Proportion	Area	Proportion
Low	24767.72	11.65	25575.89	12.03	25214.92	11.86
Relatively low	14343.45	6.75	12705.08	5.98	13096.58	6.16
Medium	51728.41	24.33	55872.64	26.28	53041.69	24.95
Relatively high	58038.59	27.30	57005.43	26.81	57800.71	27.19
High	63731.84	29.97	61450.97	28.90	63456.08	29.84

to the NDM. Under the ECM, the areas of low, relatively high, and high habitat quality were largely consistent with the NDM, with proportional differences of only 0.21%, 0.11%, and 0.13%, respectively. However, the area of relatively low habitat quality significantly decreased, with a proportional reduction of 0.59%, while the area of medium habitat quality increased significantly, with a proportional increase of 0.62%. Spatially, the distribution area of medium habitat quality increased, while low value areas showed a trend of contraction, indicating a certain degree of improvement in habitat quality. The distribution of high habitat quality remained primarily concentrated in the western, northern, and southeastern mountainous regions of the county, highlighting the importance of mountainous areas to the ecosystem of Xiuning County. The aggregation effect of constructed land significantly decreased, and the expansion trend of low habitat quality areas in the eastern region slowed, resulting in an overall enhancement of habitat quality compared to the NDM.

Further analysis indicates that there are certain differences in habitat quality in Xiuning County under the three development scenarios in terms of scale and spatial distribution; however, the hierarchical structure and spatial pattern of future habitat quality have not undergone fundamental changes. In terms of hierarchical structure, the areas and proportions of the five quality levels in the three development scenarios exhibit the same sequential structure, following the order of "high > relatively high > medium > low > relatively low". The combined proportion of high and relatively high quality areas exceeds 50%, while the combined area of low and relatively low quality does not exceed 20%. This suggests that high and relatively high habitat quality are the dominant types in Xiuning County, indicating that habitat quality will continue to be in a favorable state in the future. Regarding spatial patterns, the spatial distribution of habitat quality in Xiuning County across the three development scenarios still exhibits a clear characteristic of "high peripheral, low central". Additionally, the unique "mountain-city" dual-core spatial structure formed by high and low habitat quality areas, represented by the western mountainous regions and the central urban area, remains a prominent feature. In the future, the spatial pattern of habitat quality in Xiuning County, based on "mountain-city symbiosis", will continue to be preserved and developed.

4.5. Spatial Regulatory Zoning

The spatial regulatory zoning of habitat quality is a concrete application of the simulated prediction results of habitat quality, providing references for urban ecological environment management decisions, policy formulation, and planning layouts. Based on the simulated prediction results of habitat quality for 2030, habitat quality regulatory zones are delineated using the 21 towns of Xiuning County as the basic spatial units. This approach offers a scientific basis for future habitat quality management and policy implementation, guiding differentiated management and sustainable development of the ecological environment in each town. First, the average habitat quality values for each town under the three development scenarios are calculated (**Table 10**). Then, the natural breakpoint method is applied to classify the 21 towns into five habitat quality grade zones, which are further consolidated into three habitat quality regulatory zones. This result in alternative ecological environment management strategies for Xiuning County under the three development scenarios, laying the groundwork for making ecological environment management decisions based on multi-scenario comparisons.

Table 10. Statistics on the average habitat quality index of 21 towns in Xiuning in 2030.

Town	NDM	UDM	ECM	Town	NDM	UDM	ECM
Lantian	0.732424	0.725931	0.732125	Shangshan	0.509667	0.502428	0.505282
Qiyun Mountain	0.619187	0.593001	0.610298	Wucheng	0.616137	0.606526	0.614249
Wan'an	0.513331	0.504832	0.509357	Donglinxi	0.571771	0.566596	0.568212
Haiyang	0.551783	0.518963	0.536934	Yucun	0.586816	0.584771	0.586009
Weiqiao	0.621181	0.556957	0.600143	Yuanfang	0.673658	0.673042	0.674155
Xikou	0.677965	0.657462	0.662144	Baiji	0.656206	0.654224	0.653975
Yuetan Lake	0.616233	0.591255	0.598262	Shandou	0.638294	0.613679	0.638890
Liukou	0.872448	0.872476	0.872353	Huangjian	0.796879	0.796167	0.796521

Continued

Wangcun	0.846445	0.847071	0.845576	Longtian	0.679656	0.674540	0.675228
Banqiao	0.716814	0.718182	0.715557	Lingnan	0.672795	0.656981	0.662116
Hecheng	0.765583	0.765355	0.763506				

According to Table 10, under the three development scenarios of NDM, UDM, and ECM, Liukou Town has the highest average habitat quality values, recorded at 0.872448, 0.872476, and 0.872353, respectively, while Shangshan Town has the lowest average values at 0.509667, 0.502428, and 0.505282. Overall, the habitat quality values of the 21 towns show minimal variation across the three development scenarios, indicating that the habitat quality in Xiuning County remains relatively stable without significant leaps in change. However, Weiqiao is an exception, with average values of 0.621181 and 0.600143 under NDM and ECM, respectively, which are noticeably higher than the 0.556957 under the UDM. Furthermore, while the majority of towns exhibit higher average habitat quality values under the NDM and ECM compared to the UDM, three towns—Liukou, Wangcun, and Banqiao—show higher habitat quality values under the UDM. Additionally, Hecheng and Baiji Towns are also noteworthy, as their average habitat quality values under the UDM exceed those under the ECM.

The habitat quality grade zones and regulatory zones for the 21 towns in Xiuning County under the three development scenarios are shown in Table 11 and Figure 12. Under the NDM, there are 4 towns in the lowgrade, 6 in the relatively lowgrade, 5 in the mediumgrade, and 3 each in the relatively high and highgrade. The habitat quality grade zones under the UDM and ECM are largely consistent with those of the NDM, although there are differences regarding Weiqiao and Shandou. In the UDM, Weiqiao is classified as lowgrade, while Shandou is classified as relatively lowgrade. In the ECM, Weiqiao is classified as relatively lowgrade, while Shandou is classified as mediumgrade.

Table 11. The grade zones and regulatory zones of habitat quality in Xiuning in 2030.

Regulatory Zone	Habitat Quality Grade	NDM	UDM	ECM
key development zone	Low	Haiyang, Wan'an, Shangshan, Donglinxi	Haiyang, Wan'an, Shangshan, Donglinxi, Weiqiao	Haiyang, Wan'an, Shangshan, Donglinxi
	Relatively low	Qiyun Mountain, Weiqiao, Yuetan Lake, Wucheng, Shandou, Yucun	Qiyun Mountain, Yuetan Lake, Wucheng, Shandou, Yucun	Qiyun Mountain, Weiqiao, Yuetan Lake, Wucheng, Yucun
flexible development zone	Medium	Xikou, Lingnan, Longtian, Yuanfang, Baiji	Xikou, Lingnan, Longtian, Yuanfang, Baiji	Xikou, Shandou, Lingnan, Longtian, Yuanfang, Baiji
optimized development zone	Relatively high	Lantian, Banqiao, Hecheng	Lantian, Banqiao, Hecheng	Lantian, Banqiao, Hecheng
	High	Liukou, Wangcun, Huangjian	Liukou, Wangcun, Huangjian	Liukou, Wangcun, Huangjian

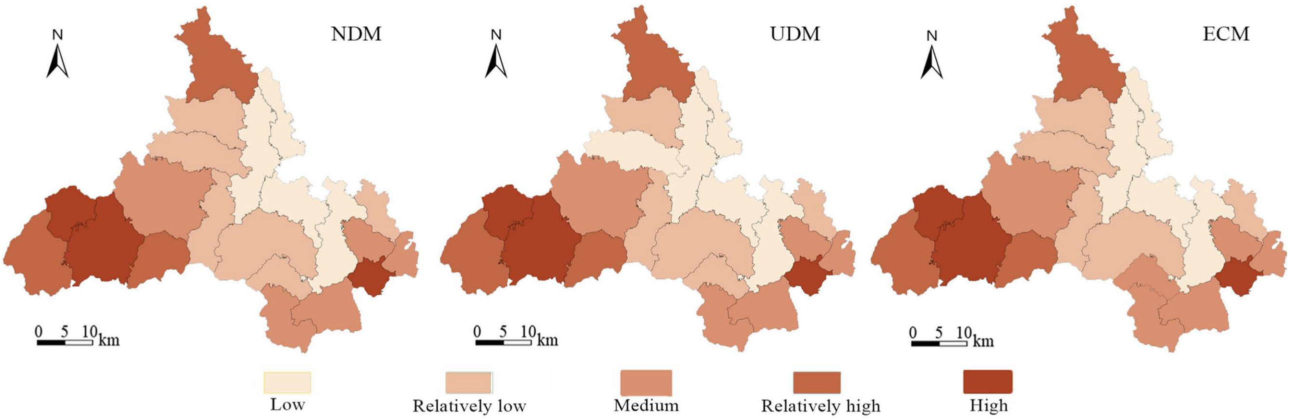

Figure 12. Habitat quality grade zoning in Xiuning in 2030.

Furthermore, from the perspective of ecological environment planning and management, low and relatively lowgrade areas are designated as key development zones, mediumgrade areas as flexible development zones, and relatively high and highgrade areas as optimized development zones, resulting in three habitat quality regulatory zoning schemes. According to **Table 11** and **Figure 12**, under the NDM, the key development zone includes 10 towns, the flexible development zone includes 5 towns, and the optimized development zone includes 6 towns. The regulatory zoning scheme under the UDM is identical to that of the NDM. In the ECM, Shandou is classified as a flexible development zone, while the regulatory zoning of other towns aligns completely with the previous two models. The key development zone consists of lowquality habitat areas, primarily in the eastern and central regions of the county. Future efforts should focus on ecological environment protection and restoration in these towns, actively planning major ecological construction projects, while reasonably controlling the expansion of construction land to continuously improve habitat quality. The flexible development zone encompasses mediumquality habitat areas, mainly including some towns on the southeastern border of the county, and can serve different spatial functions based on varying urban development strategies. For instance, when urban expansion is prioritized, it can function as reserve space for future development; when contraction and protection are prioritized, it can act as ecological buffer areas, thus maximizing environmental protection. The optimized development zone consists of highquality habitat areas, which are the main aggregation zones for Xiuning County's ecological resources and elements, forming the basis for biodiversity and sustainable development. It is essential to further optimize protection measures based on current conditions, solidify existing habitat quality, and ensure it does not decline, thereby establishing it as a core area for regional ecological protection and conservation.

5. Discussion

5.1. Has Xiuning Fulfilled the National Task Requirements?

Since the 21st century, rapid urbanization has become the mainstream trend in

China (Wang et al., 2019), leading to significant pressure on urban ecological environments and resulting in various ecological issues (Li et al., 2018; Xia et al., 2020). In response, the Chinese government initiated the major function zone development strategy in 2006 (Fan et al., 2012; Liu et al., 2017; Fan et al., 2019), aiming to categorize the country's land space into four functional zones: optimized development zones, key development zones, restricted development zones, and prohibited development zones (Fan et al., 2012). Located in the heart of the mountainous region of southern Anhui, Xiuning County boasts a forest coverage rate of 83.52% and features 26 peaks over 1000 meters in elevation, making it a typical mountain city. Overall, Xiuning County has superior natural ecological conditions, with a complete forest ecosystem. It is an important natural ecological protection area, forest park, geological park, and ecological tourism area, providing significant ecological functional value. It is one of the key ecological functional zones for biodiversity conservation and water source conservation in the country, and it serves as an important ecological barrier in the Yangtze River Delta region. Consequently, Xiuning has been designated as a national-level key ecological functional area, with much of its territory classified as restricted and prohibited development zones in the national major function zone planning. This indicates that the primary function assigned to Xiuning County by the state is ecological protection.

So, has Xiuning County met the national objectives over the past 20 years? Research shows that between 2000 and 2020, the areas of low, relatively low, and medium habitat quality decreased by a total of 4485.21 hectares, while the areas of relatively high and high habitat quality increased correspondingly by the same amount. Furthermore, the area of improved habitat quality (14782.21 hectares) far exceeds the area of degraded habitat quality (3035.38 hectares). This indicates that habitat quality in Xiuning County has improved over the past 20 years, suggesting that Xiuning has achieved the national goals set for it and has overall fulfilled the task requirements for ecological protection.

5.2. Which Prediction Scenario Should Xiuning Choose?

The study has simulated and predicted habitat quality for Xiuning County in 2030, resulting in predictions under three development scenarios and subsequently proposing three habitat quality regulatory zoning schemes. From the perspective of implementation, only one scenario can be selected as the basis for future ecological environment protection and construction. Therefore, which should Xiuning County choose as the final scheme? The study suggests that Xiuning County should prioritize the ECM as the optimal choice for several reasons. First, as a national-level key ecological functional area, Xiuning County must adhere to national requirements by making ecological protection the dominant task in urban development, achieving urbanization while ensuring green and sustainable development. Second, examining the scenarios themselves reveals that under the NDM, the total area of low and relatively low habitat quality is 39111.17 hectares, accounting for

18.40%, while the combined area of medium, relatively high, and high habitat quality is 173498.84 hectares, accounting for 81.60%. In contrast, under the ECM, the corresponding areas and proportions of habitat quality are 38311.50 hectares and 18.02%, and 174298.50 hectares and 81.98%, respectively. This comparison indicates that the ECM would maintain higher habitat quality.

Finally, it is essential to recognize the pressures and challenges Xiuning County faces regarding ecological environment protection. The county features a diverse ecological environment and complex topography. While it has met national goals over the past 20 years, there remains a phenomenon of conversion of ecological land—such as cropland, forestland, grassland, and water bodies—into construction land, which can lead to habitat quality decline. Moreover, urbanization inevitably increases the demand for construction land, which not only consumes a significant amount of land but also causes severe disturbances and threats to the surrounding ecological environment, further diminishing habitat quality. Thus, the key to achieving sustainable development in Xiuning County lies in alleviating the conflicts and contradictions between ecological protection and urban development, while continuing to maintain a habitat quality spatial pattern based on "mountain-city symbiosis". This reality objectively necessitates the adoption of the ECM.

5.3. Suggestions for the Future Development of Habitat Quality

In summary, Xiuning County should prioritize the habitat quality regulatory zoning scheme under the ECM for the future. Based on this, the following development recommendations are proposed: First, Xiuning County should align its actions with the national major function zone positioning and the designation as a key ecological functional area. It should enhance ecological protection and restoration according to the definitions of key development zones, flexible development zones, and optimized development zones. This includes increasing the area proportions of forests, grasslands, and water bodies, maintaining and improving the capacity for ecological product supply, and further enhancing habitat quality. Second, for the key development zones, Xiuning County needs to regulate the pace and rhythm of urbanization, restraining development activities to improve land use efficiency. Strict control should be exercised to prevent blind expansion of construction land, thereby laying a foundation for further improving habitat quality. Thirdly, regarding the flexible development zones, Xiuning County should prioritize their function as ecological buffers to better preserve the natural ecological baseline. Even if construction projects are necessary, their nature must be strictly regulated, with appropriate allocation of non-polluting, efficient, and low-energy-consumption developments. Finally, for the optimized development zones, Xiuning County should focus on protecting various levels and types of natural protected areas, including the Hengjiang National Wetland Nature Park, Qiyun Mountain Scenic Area, Liugujian Nature Reserve, Lingnan Nature Reserve, and Huangshan Salamander Nature Reserve. Additionally, it should actively plan a series of major ecological environment protection and restoration projects from the perspectives of biodiversity, soil and water conservation, and water source protection. Suggested projects include comprehensive water environment management and restoration, ecological protection and restoration of forested mountains, and ecological restoration of mining areas, thereby solidifying the foundation for further improving habitat quality throughout the county.

6. Conclusion

This study utilized the InVEST-PLUS coupled model to analyze the spatiotemporal evolution characteristics of land use and habitat quality in Xiuning County, and conducted multi-scenario simulations and predictions for future habitat quality development. Based on the predictive results, habitat quality regulatory zoning schemes were proposed. The findings of this study can provide theoretical references and scientific bases for ecological protection and developmental construction in Xiuning County and similar mountain cities. The main conclusions of the research include:

1) The land use types in Xiuning County are primarily dominated by forestland, followed by cropland, grassland, construction land, and water. From 2010 to 2020, a notable characteristic of land use change in Xiuning County was the increase in construction land and the decrease in cropland, while other land use types also experienced varying degrees of change. The mutual conversion among cropland, construction land, and forestland was the dominant type of land use transition, with the conversion of cropland to construction and forestland being particularly pronounced.

2) Analysis using the InVEST model indicated that between 2000 and 2020, low habitat quality areas in Xiuning County decreased while high habitat quality areas increased. Furthermore, the area of improved habitat quality far exceeded the area of degraded habitat quality, demonstrating that habitat quality in Xiuning County has improved and increased over the past 20 years, meeting national objectives.

3) Predictions from the PLUS model for 2030 suggest that under the NDM, UDM, and ECM, forestland will remain the dominant land type in Xiuning County, while construction land, cropland, grassland, and water will undergo localized changes.

4) The InVEST-PLUS coupled model forecasts the habitat quality in Xiuning County for 2030 under the three scenarios, indicating that habitat quality is highest under the ECM, followed by the NDM, with the lowest quality under the UDM.

5) Based on the simulated predictions of habitat quality, the 21 towns in Xiuning County were classified into three habitat quality regulatory zoning categories: key development zones, flexible development zones, and optimized development zones. The study recommends that Xiuning County adopt the regulatory zoning scheme under the ECM, and concludes with targeted development suggestions.

The study highlights several areas that require further exploration. For instance, land use changes exhibit significant uncertainty and are influenced by multiple factors, including economic, social, and natural environmental elements. Future research will incorporate additional driving factors into simulations to achieve more accurate predictive results. Additionally, some parameter settings in the InVEST and PLUS models rely on professional experience and involve a degree of subjectivity. Optimizing model parameters to enhance the scientific reliability of research findings will be an important direction for future studies. To enhance the objectivity and robustness of future research outcomes, subsequent work could focus on employing sensitivity analysis to quantify the degree of perturbation that key parameters introduce to the simulation results, or incorporate expert knowledge calibration based on the Delphi method, thereby systematically optimizing parameter assignments and reducing subjective uncertainty.

Mountain cities represent a complex "mountain-city" ecological system characterized by intricate ecological environments and varied topographies. This complexity leads to more intricate yet fragile "human-land" relationships. The evolution and simulation prediction of habitat quality in such regions hold significant value and importance, though they remain an area of ongoing deepening and refinement. Using Xiuning County as a typical case study, this research aims to provide a reference for habitat quality studies in mountain cities. In the future, selecting a broader range of sample cities for in-depth exploration could contribute to a more scientific guiding role in achieving sustainable development in mountainous urban areas.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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