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Article

Research on the Evolution of Habitat Quality in Yunnan Province Based on the InVEST Model

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Abstract: Evaluating Habitat Quality through land use and cover change is of great significance for biodiversity and the sustainable development of the ecological environment. This study explores the spatiotemporal changes in land use and Habitat Quality in Yunnan Province in 1990, 2000, 2010, and 2022 by combining the Habitat Quality module of the InVEST model with ArcMap software. The results indicate that: (1) The area of forest land in Yunnan Province is the largest, followed by grassland and cultivated land, with the area of construction land increasing year by year and the area of cultivated land decreasing significantly; (2) The main type of land use conversion in Yunnan Province is from cultivated land to construction land, with other land conversion types being relatively balanced, and the area of water bodies and unused land continuously increasing; (3) The overall level of Habitat Quality in Yunnan Province is relatively high, with high and higher-grade areas accounting for about 79%, and the average Habitat Quality maintained above 0.8; (4) Before 2010, the Habitat Quality in Yunnan Province showed a spatial characteristic of lower in the east and higher in the west. After 2010, there was a degradation in Habitat Quality, showing a spatial characteristic of lower in the east and west, and higher in the central region.

Keywords: Land use, InVEST model, Habitat Quality, Yunnan Province

1. Introduction

Habitat refers to the place where organisms live and reproduce, consisting of both biological and non-biological environments[1]. The degradation of habitat has a direct impact on biodiversity[2]. Habitat Quality refers to the environment's ability to provide for the survival and livelihood of organisms, with Habitat Quality types classified from low to high. The evaluation results have significant guiding implications for ecological security and sustainable development[3]. Land Use/Cover Change (LUCC) can visually present the characteristics of surface environmental changes, which in turn can affect regional ecological environmental quality[4-6]. Therefore, conducting Habitat Quality evaluations and analyzing Habitat Quality evolution are of great significance for biodiversity conservation and sustainable development.

In recent years, Habitat Quality evaluation has gradually become a research hotspot, with a large number of scholars using the InVEST model combined with ArcMap software to evaluate Habitat Quality across various regions. Based on the evaluation results, simulations or predictions are conducted using models such as CA-Markov[7], MaxEnt[8], PLUS[9-11], and FLUS[12], which play a crucial role in guiding the future land resource structure, biodiversity conservation, and sustainable development of the study areas. Currently, most studies focus on analyzing past changes in habitat quality, with the aim of exploring the patterns and conditions of habitat changes. Future research can simulate and predict changes in habitat quality in specific years based on past changes in habitat quality.Yunnan Province, located in the southwestern border of China, boasts a unique geographical location that has contributed to its complex and diverse ecosystems. However, with the continuous advancement of urbanization and issues such as overexploitation of resources, Yunnan's ecosystems are facing severe challenges. Therefore, this study utilizes the InVEST model to assess the Habitat Quality of Yunnan Province, aiming to provide references for land structure and sustainable development in Yunnan Province.

2. Rigional Overview

Yunnan Province is located in the southwestern border of China, spanning from 21°8′ to 29°15′ north latitude and 97°31′ to 106°11′ east longitude. It borders Guangxi and Guizhou to the east, Tibet to the northwest, Myanmar to the west, and Laos and Vietnam to the south. Yunnan governs a total of 16 cities and prefectures, with a total land area of 394,000 square kilometers, accounting for 4.1% of the country's total land area. Known as the "Kingdom of Plants," "Kingdom of Animals," and the "World Garden," Yunnan is one of the regions with the richest biodiversity globally. Its unique ecosystem is shaped by natural landscapes such as mountains, valleys, rivers, and lakes. The northwest of Yunnan is dominated by the Hengduan Mountains, while the central and southern parts are the main body of the Yunnan-Guizhou Plateau. The geographical features of high mountains and deep valleys are formed due to the north-high-south-low terrain. Coupled with a diverse climate ranging from tropical to cold temperate zones, it provides a variety of living environments for various species. Major rivers like the Jinsha River, Lancang River, and Nujiang River traverse the province, providing abundant water resources for the ecosystem. Nine plateau lakes, including Erhai Lake, Lugu Lake, and Fuxian Lake, serve as important habitats for biodiversity. The geographical location of Yunnan Province is shown in Figure 1.

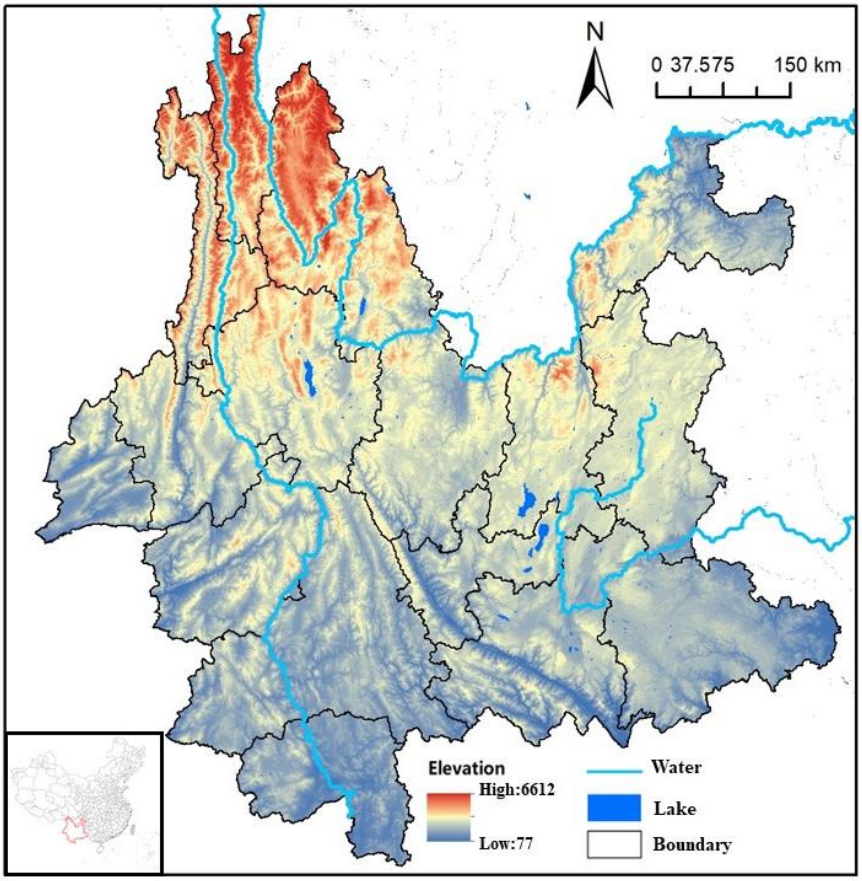

Figure 1. Geographical Location Map of Yunnan Province

3. Data Source and Research methods

3.1. Data Source

The study utilizes four phases of land use data from 1990, 2000, 2010, and 2022 (Source: Resource and Environmental Sciences and Data Center, Chinese Academy of Sciences, http://www.resdc.cn/). The spatial resolution is 30 meters. Based on land resources and their utilization attributes, the data is classified into six primary categories: cultivated land, forest land, grassland, water area, construction land, and unused land. Furthermore, it is divided into 25 secondary categories according to natural attributes (China's Multi-temporal Land Use/Land Cover Remote Sensing Monitoring Data Classification System). Administrative vector boundaries were downloaded from the Resource and Environmental Sciences and Data Center website of the Chinese Academy of Sciences (http://www.resdc.cn/). DEM data originates from ASTER GDEM data on the Geospatial Data Cloud (http://www.gscloud.cn/),

with a resolution of 30 meters, a planar accuracy of 30 meters, and an elevation accuracy of 20 meters. The Habitat Quality parameters for the InVEST model were selected based on existing research both domestically and internationally.

3.2. Research methods

(1) Analysis of Single Land Use Dynamics

The single land use dynamics quantitatively reflects the speed of land change, focusing primarily on the annual rate of change in the quantity of different land use types during the study period. The study selects a single land use indicator to analyze the changes in land use in Yunnan Province over multiple years, quantifying the speed of land change in Yunnan. The research formula refers to [13], where *K* represents the land use dynamics during a certain period, *Ua* and *Ub* respectively represent the quantity of a certain land use at the beginning and end of that period, and *T* represents the time interval. The expression formula for analyzing single land use dynamics is as follows:

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

(2) Comprehensive Land Use Transition Matrix

The Comprehensive Land Use Transition Matrix is the application of the Markov model in land use change, quantitatively demonstrating the dynamic information of mutual transformation among land use types within a certain period to analyze the transformation between different land types. The transition matrix references the formula where *Sij* represents the land area transferred from land type *i* at the beginning period to land type *j* at the end period; *n* represents the total number of land use categories. The expression formula [4] for the Comprehensive Land Use Transition Matrix is as follows:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & \cdots & S_{1n} \\ S_{21} & S_{22} & S_{23} & \cdots & S_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & S_{n3} & \cdots & S_{nn} \end{bmatrix} \tag{2}$$

(3) For the Habitat Quality assessment in the InVEST model study

The Habitat Quality module of the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model, jointly developed by Stanford University, the World Wide Fund for Nature, and The Nature Conservancy, was selected to calculate the Habitat Quality index. The Habitat Quality index ranges from 0 to 1, with a higher value indicating better Habitat Quality. The calculation formula[3] is as follows:

$$Q_{xj} = H_j \left(1 - \left(\frac{D_{xj}^z}{D_{xj}^z + k^z}\right)\right) \tag{3}$$

In the formula, *Qxj* represents the Habitat Quality index of grid patch *x* in land use type *j*; *Hj* represents the habitat suitability of land use type *j*; D_{xj}^z represents the habitat degradation degree of grid *x* in land use type *j*; *z* indicates the default parameter of the model, which is a normalization constant and typically takes a value of 2.5; *k* represents the half-saturation constant and typically takes a value of 0.5.

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{W_r}{\sum_{r=1}^{R} W_r}\right) r_y i_{rxy} \beta_x S_{jr} \tag{4}$$

In the formula, D_{xj} represents the habitat degradation index of grid *x* in land use type *j*; *R* is the number of threat factors; *Yr* is the number of grids for threat factors; *Wr* is the weight of threat factor *r*; r_y is the stress value of grid *y*; i_{rxy} is the stress level of r_y on grid *x*; βx represents the accessibility of threat factors to grid *x*, ranging from 0 to 1, with values closer to 1 indicating higher accessibility; S_{jr} is the sensitivity of land use type *j* to threat factor *r*, also ranging from 0 to 1, with values closer to 1 indicating higher sensitivity.

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{r\,max}}\right) \rightarrow \text{line decay} \tag{5}$$

$$i_{rxy} = exp\left(-\left(\frac{2.99}{d_{r\,max}}\right) d_{zy}\right) \rightarrow \text{exponential decay} \tag{6}$$

This formula represents the calculation of stress level, where i_{rxy} is the distance between the habitat grid and the threat; d_{xy} denotes the linear distance between grid x and grid y; and $d_{r\,max}$ signifies the maximum distance of threat factor r.

According to the model requirements, referencing existing research in similar regions and the actual situation in Yunnan Province, paddy fields, dry land, urban construction land, rural settlements, and other construction land are identified as threat factors. The maximum influence distance, weight, and decay type of these threat factors are determined based on existing research in similar regions, with adjustments made to reflect the actual conditions of Yunnan Province. The habitat suitability and sensitivity coefficients for each land type are determined by referring to studies conducted in similar regions, as detailed in Tables 1 and 2.

Table 1. Threat source parameters

Threat factors	Maximum influence distance (km)	Weight	Attenuation type
Paddy Field	0.8	0.2	line
Dryland	1	0.4	line
Urban Construction Land	10	1	exponential
Rural Residential Areas	3	0.7	exponential
Other Construction Land	1	0.5	exponential

Table 2. The sensitivity of land use types to threat factors.

Land use type		HQ	Sensitivity coefficient				
Primary land category	Secondary land category		Paddy Field	Dryland	Urban Construction Land	Rural Residential Areas	Other Construction Land
Cultivated land	Paddy Field	0.5	0	0.3	0.8	0.5	0.4
	Dryland	0.3	0.3	0	0.7	0.5	0.6
Forest land	Forested Land	1	0.9	1	0.8	0.8	0.65
	Shrubland	1	0.9	1	0.65	0.7	0.6
	Open Forest	0.8	0.8	0.9	0.6	0.6	0.5
	Other Woodland	1	0.9	1	0.85	0.85	0.7
Grass land	High-coverage Grassland	0.8	0.4	0.5	0.55	0.6	0.35
	Medium-coverage Grassland	0.7	0.45	0.55	0.6	0.65	0.4
	Low-coverage Grassland	0.6	0.4	0.5	0.5	0.6	0.3
Water land	Rivers and Canals	0.9	0.3	0.3	0.65	0.75	0.6
	Lakes	1	0.3	0.3	0.65	0.75	0.6
	Reservoirs and Ponds	0.7	0.5	0.5	0.5	0.8	0.6
	Mudflats	0.6	0.7	0.8	0.7	0.8	0.7
	Beach Land	0.5	0.7	0.8	0.7	0.8	0.7
Construction land	Urban Construction Land	0	0	0	0	0	0
	Rural Residential Areas	0	0	0	0	0	0
	Other Construction Land	0	0	0	0	0	0

	Saline-alkali Soil	0.5	0.3	0.2	0.5	0.6	0
	Marshland	0.5	0.5	0.2	0.6	0.7	0

4. Results and Analysis

4.1 Single Land Use Dynamic Degree

Using ArcMap software, the four phases of land use maps were processed to obtain the area of each land use type, as shown in Table 3. During the period from 1990 to 2022, Yunnan Province was dominated by forest land, grassland, and farmland as its major land types. Influenced by Yunnan's unique topography and landforms, forest land occupied the largest area, followed by grassland and farmland. The area of forest land began to increase after 2010 and recovered to a similar level as in 1990 after 2022. Farmland area gradually declined during this period. Grassland area first increased and then decreased. Construction land and water areas accounted for relatively small proportions, with water area first decreasing and then increasing, while construction land area showed a steadily increasing trend, with an accelerated growth rate after 2010.

From the dynamic degree analysis, it can be seen that the dynamic degree of construction land had the highest increase, while unused land experienced the largest decrease, indicating a very dramatic degree of change, which is a testament to the rapid urbanization process during this period. The decreases in forest land, farmland, and grassland were not significant, and combined with the areas of these three land use types, it can be inferred that Yunnan Province has achieved good results in afforestation, returning farmland to forests, and grassland restoration projects. The relatively high increase in the dynamic degree of water areas, combined with the actual water area changes, suggests that this is related to the successful implementation of water conservancy projects and lake restoration projects in Yunnan Province.

Table 3. The single land use dynamic degree of Yunnan Province from 1990 to 2022.

Land use type	Area(km^2)				Dynamic Degree (%)
	1990	2000	2010	2022	1990~2022
Cultivated land	65603.93	65537.10	64906.88	63635.81	-3
Forest land	226190.90	224792.18	225168.50	226019.23	-0.07
Grass land	84116.31	85757.75	85710.80	83138.93	-1.16
Water area	3127.54	2705.15	2719.32	3568.47	14.09
Construction land	1582.12	1802.56	2089.30	4488.08	183.67
Unused land	2124.19	2076.07	2076.90	1490.20	-29.85

3.2 Comprehensive Land Use Transition Matrix

To gain a deeper understanding of land use type changes in Yunnan Province, a land use transition matrix was constructed, focusing on the primary land use types of farmland, forest land, grassland, construction land, water areas, and unused land. To facilitate the generalization of land use transitions, a chord diagram of the land use transition matrix is presented in Figure 2. Over the past 30 years, the major land use transitions in Yunnan Province have occurred between farmland and construction land. The area of construction land has continued to expand, while farmland has gradually decreased, which is attributed to the continuous outward expansion of urban boundaries during the urbanization process, gradually encroaching on farmland. Inter-transitions among farmland, forest land, and grassland have also occurred, with relatively balanced transfer areas, suggesting corresponding adjustments and conversions of land use in Yunnan Province at different times. Additionally, area transfers from grassland, forest land, and farmland to water areas have occurred, further corroborating the previous speculations. The area of unused land has shown a slight growth trend.

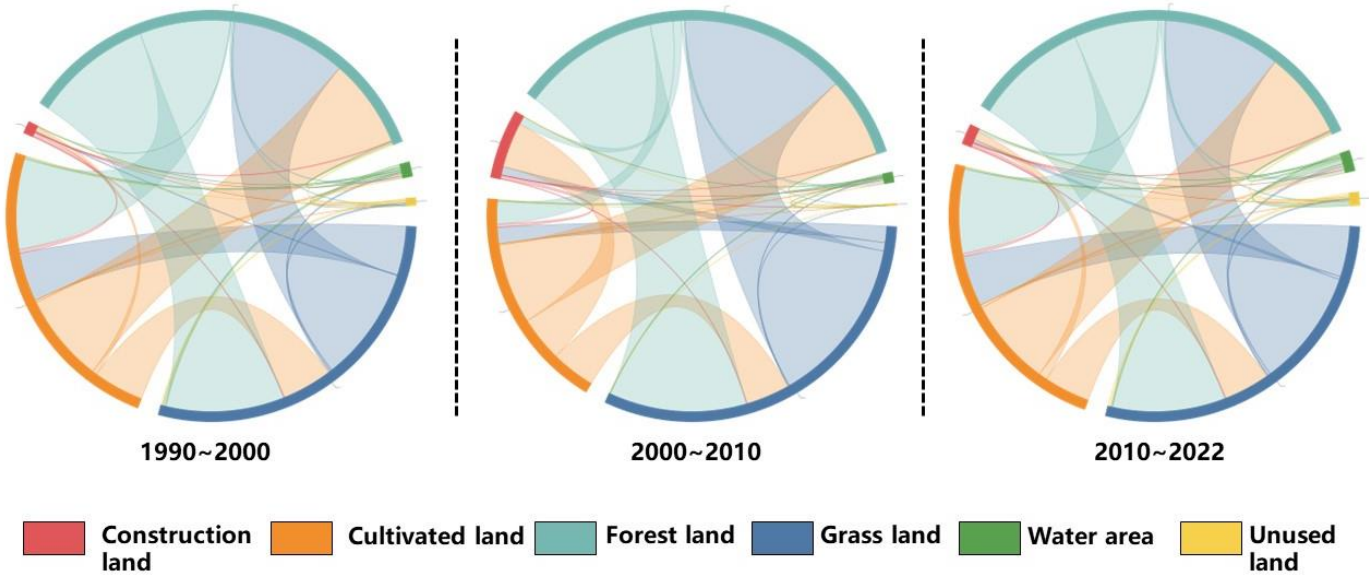

Figure 2. Chord diagram of land use transition matrix in Yunnan Province from 1990 to 2022.

3.3 Analysis of Habitat Quality Changes

After processing the land use data, hazard source data, and sensitive source data through the InVEST model, the Habitat Quality Index (HQI) for Yunnan Province was obtained, as shown in Figure 3, with corresponding area statistics presented in Table 4. The model results were then partitioned in ArcMap software based on average intervals, resulting in five Habitat Quality zones: low-level zone ($0 \leqslant HQI < 0.2$), lower-middle level zone ($0.2 \leqslant HQI < 0.4$), middle-level zone ($0.4 \leqslant HQI < 0.6$), upper-middle level zone ($0.6 \leqslant HQI < 0.8$), and high-level zone ($0.8 \leqslant HQI < 1.0$).

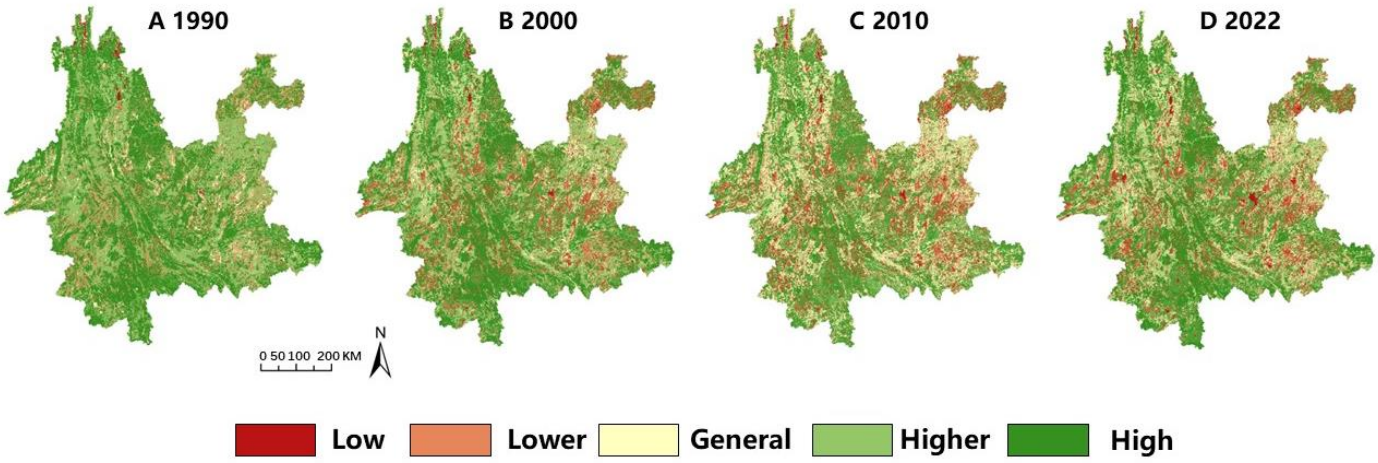

Figure 3. Changes in Habitat Quality in Yunnan Province from 1990 to 2022.

Table 4. Area and proportion of Habitat Quality in Yunnan Province from 1990 to 2022.

Habitat Quality grades	Area occupied by Habitat Quality grades/Area (km²) and proportion (%)								decrease percentage(%)
	1990	proportion	2000	proportion	2010	proportion	2022	proportion	1990 to 2022
Low	3922.75	1.02	4086.30	1.07	4385.89	1.15	6226.02	1.63	58.72
Lower	48408.60	12.65	48277.95	12.62	48173.31	12.59	48344.32	12.64	-0.13
General	19984.44	5.22	20165.60	5.27	20027.56	5.23	18783.09	4.91	-6.01
Higher	130571.98	34.12	130344.91	34.06	130406.02	34.08	127732.05	33.41	-2.17

High	179843.73	46.99	179800.41	46.99	179679.22	46.95	181251.78	47.41	0.78
Average HQ	0.8268		0.8266		0.8262		0.8246		-0.27

As shown in Figure 3, the Habitat Quality in Yunnan Province exhibited a spatial pattern of decreasing from east to west in 1990 and 2000, with the western part dominated by upper-middle and high-level zones, and the eastern part mostly below the average level. In 2010, both the eastern and western regions of Yunnan had relatively low Habitat Quality, while the central region remained stable, primarily consisting of high-level and upper-middle-level zones, indicating a decline in Habitat Quality during this period. By 2022, the Habitat Quality in Yunnan had improved compared to 2010, with a notable increase in high-level and upper-middle-level zones, overall exhibiting a spatial distribution characterized by lower levels in the east and west, and higher levels in the center.

Table 4 indicates:(1) From the perspective of overall changes in Yunnan Province, Habitat Quality is primarily at the upper-middle and high levels, with a total area of 308,983.83 km². The upper-middle level accounts for more than 33% over the years, and the high level accounts for more than 46%, with minimal fluctuations in area changes. This demonstrates that Yunnan Province has a relatively high level of Habitat Quality. In addition to the upper-middle and high levels, the lower-level Habitat Quality accounts for a relatively large proportion, exceeding 12%, while the middle and low levels have the smallest areas. The changes in the lower-middle and middle levels are insignificant, but the low-level Habitat Quality area experiences the most significant increase and decrease, exceeding 58%, which is presumed to be caused by urban and rural development.(2) From the perspective of year-to-year changes, Habitat Quality changes were not evident between 1990 and 2010, with minimal changes in the area of each level. However, from 2010 to 2022, significant changes in Habitat Quality occurred, particularly in the low-level area, which grew notably, and the lower-middle and high-level areas also increased rapidly. This is presumed to be due to the accelerated urbanization process after 2010, resulting in interconversions between land use types and more significant fluctuations in the area of Habitat Quality zones.(3) In terms of average Habitat Quality changes, Yunnan Province maintained a relatively high level of Habitat Quality from 1990 to 2022, with an average Habitat Quality above 0.8. However, the average Habitat Quality decreased from 0.8268 to 0.8246 during this period, indicating a phenomenon of Habitat Quality degradation in Yunnan Province.

5. Conclusions

Yunnan Province is located on the southwestern border of China and is an important area for environmental protection. Evaluating habitat quality analysis has a guiding role in the environmental protection of Yunnan Province. This research is based on ArcGIS analysis software and utilizes the InVEST model's habitat quality section to investigate and analyze the single land use dynamics, comprehensive land use transfer matrix, and habitat quality changes in Yunnan Province from 1990 to 2022. Three research conclusions were obtained. It is expected that the research conclusions of this study can provide guidance for the implementation focus and direction of habitat protection, ecological restoration and other engineering projects in Yunnan Province.

(1) From 1990 to 2022, Yunnan Province was dominated by forestland, grassland, and farmland as its primary land types, with forestland occupying the largest area, followed by grassland and farmland. The areas of forestland, grassland, and water bodies initially decreased and then increased. The initial decrease may be related to land use adjustments and increased water consumption in Yunnan Province, while the subsequent increase could be attributed to the Grain for Green Program (converting farmland to forest or grassland) and water conservancy projects implemented in the province. Farmland area continued to decrease, while construction land and unused land areas increased steadily, indicating the advancement of urbanization in Yunnan Province, with urban boundaries gradually expanding outwards and farmland being converted into construction land.

(2) During the period from 1990 to 2022, the primary land use type conversions in Yunnan Province occurred between farmland and construction land, as the urbanization process gradually encroached on surrounding farmland. The conversions between forestland, grassland, and farmland were relatively balanced in scale. Additionally, the areas of water bodies and unused land that received conversions from other land types continued to increase.

(3) Before 2010, the Habitat Quality in Yunnan Province exhibited a spatial pattern of lower levels in the east and higher levels in the west. However, this pattern changed after 2010, and by 2022, the overall Habitat Quality showed a spatial distribution characterized by lower levels in the east and west, and higher levels in the center, indicating a certain degree of imbalance. From 1990 to 2022, Yunnan Province maintained a relatively high overall level of Habitat Quality, with high-level and upper-middle-level zones accounting for approximately 79% of the total area, and the average Habitat Quality remaining above 0.8. During the period from 1990 to 2010, changes in Habitat Quality in Yunnan Province were not significant, but significant

changes began to occur after 2010. The accelerated urbanization process led to the degradation of Habitat Quality in Yunnan Province.

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