

Article

Ecological Zoning Based on Value–Risk in the Wuling Mountains Area of Hunan Province

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Abstract: Based on land use data from the Wuling Mountains area of Hunan Province for 2000, 2010, and 2020, we used tools such as frastats4.8 and ArcGIS10.8 to construct a model for assessing ecosystem service value and the ecological risk index. We divided the area into four regions based on ecosystem service value and ecological risk indicators, which served as the foundation for ecological zoning and a proposed strategy for an ecological security pattern that suits the ecology of the region. The results showed a general increase in both ecosystem service value and ecological risk in the study area from 2000 to 2020. The annual ecosystem service value exceeded CNY 300×10^9 , with forests providing more than 77% of this value, and the regulating services value accounted for 68% of the total value. The mean ecological risk indexes for the periods of 2000, 2010, and 2020 were 0.0384, 0.0383, and 0.0395, respectively. The sizes of the four zones within the study area remained relatively stable: the ecological barrier zone accounted for more than 53% over three years; the ecological improvement zone, approximately 32%; the ecological control zone comprised 8.62% of the total area in 2000, and this proportion rose to 9.56% in 2020. The ecological conservation zone had the smallest proportion of the total area among the four zones. Our research provides a comprehensive analytical framework for constructing ecological security patterns in other developing countries and offers a new perspective for regional ecological zoning management and conservation planning.

Keywords: ecological zoning; zoning management policies; ecosystem service value; ecological risk; the Wuling Mountains area of Hunan Province



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1. Introduction

With the acceleration of urbanization, natural ecological space has been seriously squeezed, land use has changed, and the ecological environment is deteriorating. This study argues that governance cannot be based solely on administrative divisions, whose “locality” can fragment regional ecosystems that emphasize “wholeness” [1]. So, ecological zoning is an important scientific issue in the field of ecological environmental protection and is of great significance to the construction of regional ecological security barriers; it is the basic work for optimizing the development and protection pattern of territorial space, carrying out surveys of areas with differentiated functional development, and realizing targeted zoning management.

In fact, the concept of ecological zoning has a long history, as evidenced by examples such as the zoning of habitat types by the United States Department of Agriculture [2] and China’s agricultural ecological zoning [3]. These agricultural zoning practices are typically based on geospatial elements, ensuring that boundary delineation aligns with ecosystem boundaries.

In recent years, a large amount of research has been conducted in the field of ecological zoning by scholars at home and abroad. Ecological zoning was first and most widely used in agriculture. For example, some studies have demarcated regions with similar productivity

of wheat and potato [4,5]. Furthermore, The International Institute for Applied Systems Analysis and the Food and Agriculture Organization of the United Nations (2021) have been continuously developing the agro-ecological zoning methodology for assessing agricultural resources and potential [6]. Some studies have assessed the land's potential for cultivating selected medicinal plants by analyzing the edaphic and climatological data from previous years in India, categorizing zones as optimally suitable, suitable, and less suitable [7]. As technological tools continue to be upgraded and the need for objective management increases, the application of ecological zoning is gradually expanding to other areas of the economy and society. Regarding the research object, spatial zoning elements were identified by partitioning the park into homogeneous land units aimed at suggesting to parking management and other stakeholders an approach that is scientifically sound and practical [8]. These studies have been based on a pragmatic approach to zoning, aimed at solving specific problems in life and production. With the deepening understanding of ecosystems, the indicator system for ecological zoning is gradually being oriented towards ecological health and ecological impact. Some researchers have established a framework to assess environmental vulnerability and identified ecological zones requiring development and protection solutions [9]. In addition to single environmental indicators, some studies use multiple indicators as a basis for ecological zoning. They identified and classified the ecological restoration space and the ecological protection space based on ecological spatial quality indices, ecological health indices, and ecosystem service values, which effectively guided the improvement of land space planning and the regional ecological environment management system [10–13]. Some also assessed the value and risk in the region and established a framework for ecological zones for the Upper Yellow River and the Three Gorges Reservoir area, which contributed greatly to boosting intensive and economical utilization, protecting ecological land, and balancing economic construction and environmental protection [14,15].

In summary, research on ecological zoning has yielded significant insights, providing a strong foundation for this paper. However, earlier studies have primarily focused on positive indicators for zoning, emphasizing ecological spatial quality and the value of ecosystem services. Less consideration has been given to the negative impacts and the coercive nature of human activities on the ecological environment. Most importantly, previous studies have often used ecosystem service value and ecological risk as independent indicators to characterize the ecological environment, which has not sufficiently emphasized that the ecosystem is a complex system unified by both security and coercion. In addition, previous research has paid less attention to the world's minorities and ethnic minority gathering places. Therefore, this paper combines ecosystem service value and ecological risk, constructs a “value–risk” framework based on land use, builds an innovative zoning evaluation system, and improves the zoning method.

The Wuling Mountains area of Hunan Province, as an important water conservation area, ecological function area, and ecological barrier of the Yangtze River Basin in China, plays a key role in maintaining regional ecological security. However, it has a high altitude, steep slopes, frequent natural disasters, escalating soil erosion, rock desertification, and limited ecological carrying capacity. So, ecological zoning is the key work to implement the ‘national main functional area planning’ for the Wuling Mountains area of Hunan Province. It plays a vital role in protecting the water resources of the Yangtze River Basin, ensuring the ecological security of the middle and lower reaches of the Yangtze River, and building a strong regional ecological security barrier. It is of practical significance for environmental governance and management in the Wuling Mountains area of Hunan Province. This study, taking the Wuling Mountains area of Hunan Province as an example, identifies land use types and constructs a model for ecosystem service value and ecological risk index, as well as a “value–risk” framework. Furthermore, with the help of software such as Fragstats and ArcGIS, it zones the study area and facilitates the differentiated management of these zones. It is of great significance to improve the theory of ecological zoning and construct the ecological security pattern in the region. Taking the Wuling

Mountains area of Hunan Province, which is rich in natural resources but has frequent natural disasters, as an example, the application of the ecological zoning method is of typical significance for other developing countries to maintain and improve the quality of the ecological environment, construct ecological security barriers, and implement targeted ecological management strategies.

The rest of the study is organized as follows: In Section 2, the proposed materials and methods are described in detail, which incorporate the calculation of ecosystem service value and the ecological risk index. Section 3 presents the study area, data sources and processing, and results. The discussion and corresponding suggestions are presented in Section 4. Finally, Section 5 provides the conclusions.

2. Materials and Methods

2.1. Model for Calculating Ecosystem Service Value

The standard equivalent refers to the equivalence factor used to measure the ecosystem service value (ESV) of a standard unit area. It is determined by the economic value of natural food production in 1 hm² of farmland per year based on the average national yield [16]. Previous studies have established that the economic value of one equivalence factor is equivalent to 1/7 of the economic value of natural food production in 1 hm² of farmland per year [17]. The formula for calculating the economic value of the equivalence factor is as follows:

$$E_a = \frac{1}{7} \sum_{i=1}^n \frac{m_i * p_i * q_i}{M} \quad (1)$$

where E_a represents the economic value (CNY/hm²) of the equivalence factor of the ecosystem service value in the standard unit area. The variables used include i for the type of grain, m_i for the planted area of grain type i (hm²), p_i for the average market price of grain type i (CNY/kg), and q_i for the yield per unit area of grain type i (kg/hm²). M denotes the total planted area for all grain types. In this study, the value of grain production was mostly derived from rice, corn, and soybean, considering the specific conditions of the area. To account for inflation, equivalence factors were annually adjusted using the consumer price index (CPI). The three-year average E_a was determined to be 2199.11 (CNY/hm²), with 2020 serving as the base year. Subsequently, a table of ecological service value coefficients (VC_{if}) (Table 1) was generated for the Wuling Mountains area of Hunan Province. Here, VC_{if} represents the ecological services value coefficients for the f type of ecosystem services pertaining to the i types of land use. Additionally, EC_{if} denotes the equivalent factor for the f type of ecosystem service function corresponding to the i types of land use. The calculation method for these coefficients is described below.

$$VC_{if} = EC_{if} * E_a \quad (2)$$

Table 1. Ecological service value coefficients (VC_{if}) in the Wuling Mountains area of Hunan Province (CNY/hm²).

	Ecosystem Service	Cultivated Land	Forest	Grassland	Wetland	Water Bodies	Artificial Surfaces	Bare Land
supplying services	food production	2430.02	555.28	513.13	1121.55	1759.29	0.00	21.99
	raw material	538.78	1275.48	755.03	1099.55	505.80	0.00	65.97
	water supply	−2869.84	659.73	417.83	5695.69	18,230.61	0.00	43.98
regulating services	gas regulation	1957.21	4194.80	2653.59	4178.31	1693.31	43.98	241.90
	climate regulation	1022.59	12,551.41	7015.16	7961.79	5035.96	0.00	219.91
	waste treatment	296.88	3678.01	2316.39	7961.79	12,205.05	219.91	681.72
	water regulation	3287.67	8213.67	5138.58	53,284.41	224,836.90	65.97	461.81
supporting services	soil formation and retention	1143.54	5107.43	3232.69	5079.94	2045.17	43.98	285.88
	nutrients cycling	340.86	390.34	2449.23	395.84	153.94	0.00	21.99
	biodiversity protection	373.85	4651.12	2923.48	17,306.99	5607.73	43.98	263.89
cultural services	recreation and culture	164.93	2039.67	1297.47	10,401.79	4156.32	21.99	109.56

The formula for calculating the overall ecosystem service value of the research area is as follows:

$$ESV = \sum_{i=1}^n VC_i * A_i \quad (3)$$

The total economic value of ecosystem services (ESV) in a specific research area represents the combined value of these services. Finally, the final component (A_i) is the area of the i type of land use.

The key steps for assessing ecosystem service value are as follows: (1) Calculate the equivalent factor for the f type of ecosystem service function corresponding to the i types of land use (EC_{if}). Based on the original equivalency table, we determined the equivalent factor for the f type of ecosystem service function corresponding to the i types of land use. (2) Correct the economic value of grain yield and calculate the economic value of the equivalence factor of the ecosystem service value in the standard unit area (E_a). We corrected the economic value created by grain yield per unit area in the study area using the CPI index, and further, we substituted the corrected economic value into the first equation to obtain E_a . (3) Calculate the area of the i type of land use (A_i) in ArcGIS. (4) Calculate the total ecosystem service value. We substituted the above results into the second and third equations to obtain the total ecosystem service value of the study area. (5) Visualize the results. We visualized the results using kriging interpolation in ArcGIS.

2.2. Model for Calculating the Ecological Risk Index

The ecological risk index is calculated for each evaluation unit and assigned to its center point, representing the ecological risk index of each unit. The landscape ecological risk index is derived from the landscape disturbance index, landscape vulnerability index, and landscape loss index [18]. The formulas are presented below.

$$ERI_k = \sum_{i=1}^n \frac{A_{ki}}{A_k} * R_i \quad (4)$$

where the landscape ecological risk index for the k -th evaluation unit is represented by ERI_k . A_{ki} denotes the area of the i -type landscape within the k -th evaluation unit. Additionally, A_k represents the total area of the k -th evaluation unit, and R_i signifies the ecological loss degree index of the i -type landscape.

The landscape loss index (R_i) serves as a measure to assess the ecological risks and losses induced by land use change in the natural ecosystem. The calculation formula is as follows:

$$R_i = V_i * E_i \quad (5)$$

The landscape vulnerability index (V_i) quantifies the sensitivity and resistance of a landscape type to external disturbances; E_i is the landscape disturbance index.

$$E_i = a * C_i + b * N_i + c * F_i \quad (6)$$

where C_i is the landscape fragmentation index; N_i is the landscape isolation index; and F_i is the landscape dimensionality index. The weighting coefficients a , b , and c were employed to assign relative importance to each variable, with values of 0.5, 0.3, and 0.2 [19], respectively.

The landscape fragmentation index (C_i) refers to the extent of landscape partitioning within a certain area caused by natural or anthropogenic interferences. The formula for calculating this is as follows:

$$C_i = n_i / A_i \quad (7)$$

where n_i denotes the count of patches present in the classification of landscape category i , and A_i is the area of landscape class i within the same study area.

The landscape isolation index (N_i) is a measure of the degree of separation between individuals in different patches within a specific type of landscape. The calculation formula is as follows:

$$N_i = \left(\frac{A}{2A_i} \right) * \left\{ \left(\frac{n_i}{A} \right)^{\left(\frac{1}{2} \right)} \right\} \quad (8)$$

The variable A denotes the total area of the landscape.

The landscape dimensionality index (F_i) refers to the complexity of patches and landscape patterns within a certain area or observation range, and the formula for calculating it is as follows:

$$F_i = \left\{ 2 \ln \left(\frac{P_i}{4} \right) \right\} / \ln(A_i) \quad (9)$$

The numerical range of P_i is theoretically between 1 and 2, where P_i denotes the perimeters of a landscape of class i .

The key steps for assessing the ecological risk index are as follows: (1) segment and split the evaluation units using ArcGIS; (2) extract land use data according to the split evaluation units; (3) derive the area of landscape class i (A_i), the perimeters of landscape class i (P_i), and the count of patches (n_i) using Fragstats; (4) calculate the ecological risk index for the study area by substituting the formula; (5) visualize the data using kriging interpolation with ArcGIS.

3. Empirical Analysis

3.1. Study Area

The Wuling Mountains area of Hunan Province is a gathering place of ethnic minorities. In 2020, the total population of the area accounted for approximately 25.49% of Hunan Province's total population. The region is home to over 30 ethnic minorities, including Tujia, Miao, Dong, Bai, Hui, and Yao. Covering approximately 86,000 square kilometers, this area consists of 37 counties and urban regions in Hunan Province. Its geographical coordinates range from 109° E to 112° E and 26° N to 30° N (Figure 1). The area belongs to the climate of transition from subtropical to warm zones and is characterized by abundant resources and a unique natural landscape, with Lishui, Zishui, and Yuanjiang flowing through it. However, it has a high altitude, steep slopes, frequent natural disasters, escalating soil erosion, rock desertification, and limited ecological carrying capacity.

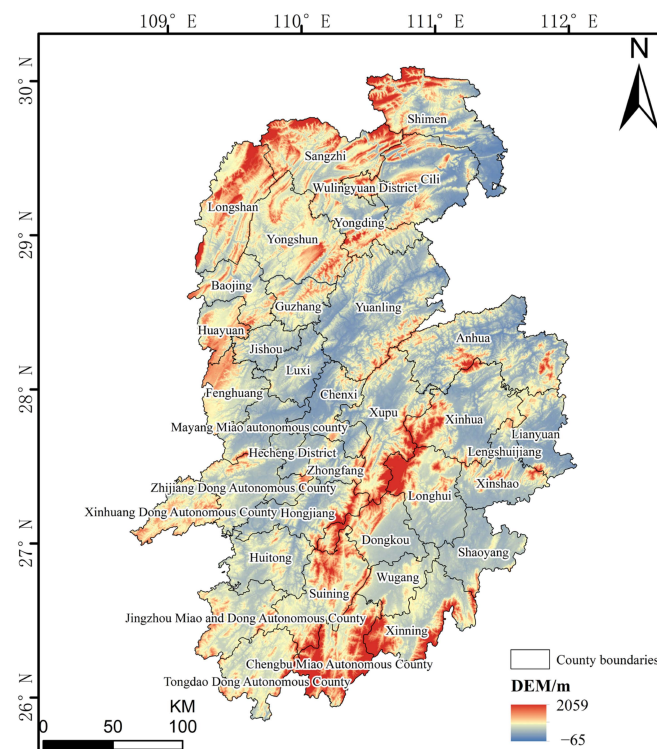


Figure 1. Location of the study area.

3.2. Data Sources and Processing

The data used in this study were as follows: (i) Land use data for the study area in 2000, 2010, and 2020 were obtained from the GlobeLand30 database of global land cover data on 20 January 2023), which provided global land cover data with a resolution of 30 m. The database categorized land use types into several categories, including cultivated land, forest, grassland, shrubland, wetland, water bodies, tundra, artificial surfaces, bare land, glaciers, and permanent snow and ice. (ii) Demographic, social, and economic data were retrieved from the official website. The associated area vector data were provided by the 1:1 million National Basic Geographical Information Database (Results 1:100 ten thousand (<https://www.webmap.cn>, accessed on 21 December 2023)) and processed using ARCGIS10.8 to obtain the relevant boundary vector data for the study area. The digital elevation model (DEM) was derived from the Geospatial Data Cloud (geospatial data cloud (<https://www.gscloud.cn/>, accessed on 21 December 2023)). Other socioeconomic data were obtained from the National Bureau of Statistics, “Hunan Statistical Yearbook”, and “Compilation of National Agricultural Product Cost and Benefit Data”.

The three-phase remote sensing images underwent registration, band combination, mosaic, geometric clipping, and other processing using ArcGIS 10.8 software. The land cover classification of the study area was determined based on the 2017 national standard for “Current Land Use Classification”, considering the landscape characteristics of the research area and our specific research goals. Seven types of land cover were found in the study area: cultivated land, forest, grassland, wetland, water bodies, artificial surfaces, and bare land.

The study area was divided into 3420 evaluation units, revealing a spatial distribution of landscape patterns characterized by both heterogeneity and homogeneity, as shown in Figure 2. The ESV and ERI of the Wuling Mountains area of Hunan Province were estimated and assigned to the center point of the evaluation unit.

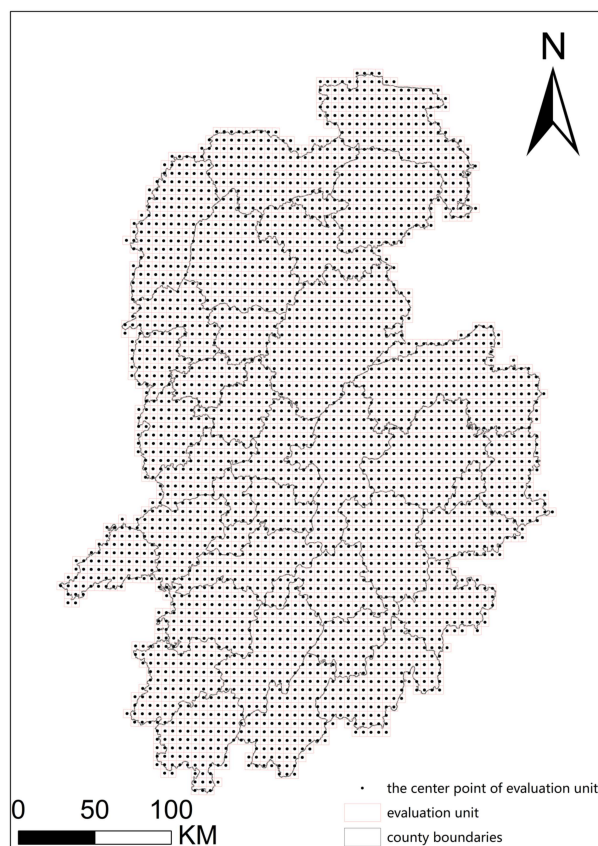


Figure 2. Division of the evaluation units.

3.3. Results

3.3.1. Land Use Changes

Based on remote sensing data and ArcGIS analysis, the changes in land use structure in the Wuling Mountains area of Hunan Province from 2000 to 2020 could be determined. During this period, forest cover comprised over 64% of the study area, making it the dominant land use type, followed by cultivated land, which accounted for approximately 26% of the total area. Overall, there were significant absolute changes in land use across the study area, along with a smaller proportion of relative changes. However, in 2020, the emergence of bare land was observed. The land use transfer map can be seen in Figure 3.

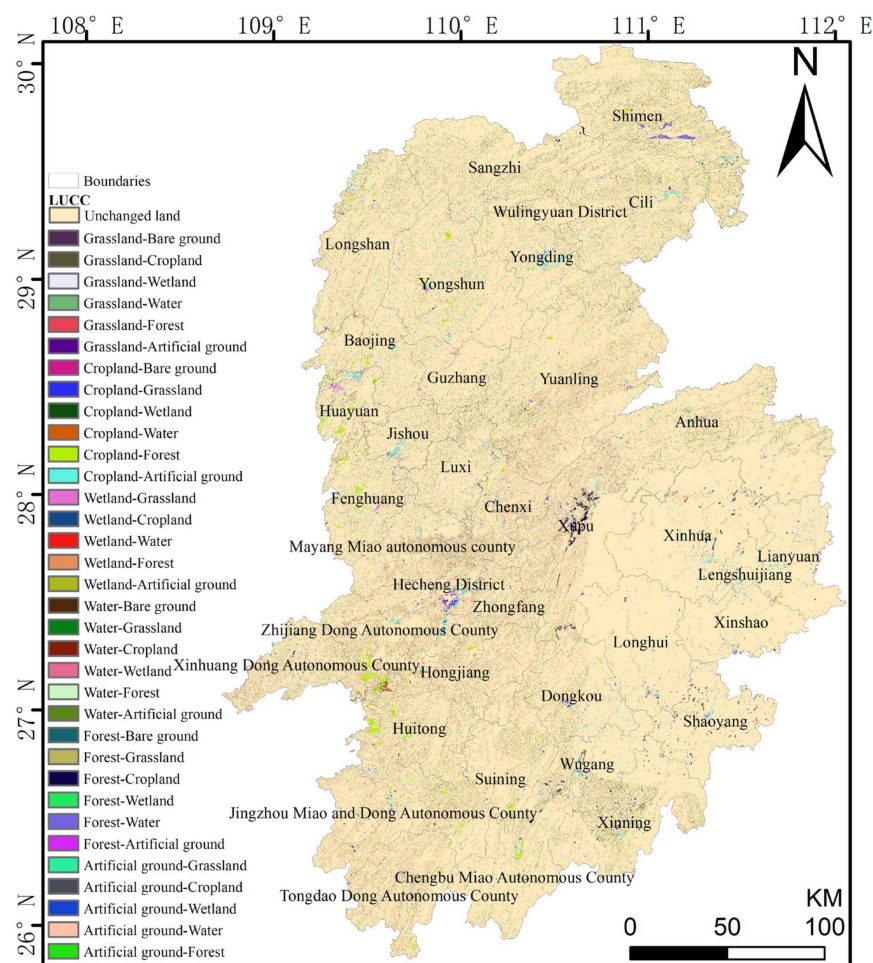


Figure 3. Land use transfer.

Table 2 presents the land use transfer matrix for the Wuling Mountains area of Hunan Province, illustrating the absolute and relative changes in land use types. The absolute changes encompassed an area of 7765.28 km², representing over 9% of the total area, while the relatively changed area was 950.48 km². Among the transferred-out land use types, cultivated land accounted for the largest portion, totaling 822.52 km², followed by grassland (98.16 km²) and forest (29.80 km²). Meanwhile, wetlands, water bodies, artificial surfaces, and bare land were net transfers in land use types, with respective areas of 4.97 km², 173.11 km², 764.72 km², and 7.68 km². Notably, cultivated land constituted 86.50% of the total area transferred out, primarily converted into forest and artificial surfaces. Regarding inward transfer, artificial surfaces accounted for the highest proportion, comprising 80.50% of the total transferred-in area, mostly originating from cultivated land and forest. Furthermore, the emergence of bare land as a new land use type in the Wuling Mountains area of Hunan Province was absent in 2000 and 2010.

Table 2. Land use matrix of transition in the Wuling Mountains area of Hunan Province from 2000 to 2020 (km²).

	2020	Cultivated Land	Forest	Grassland	Wetland	Water Bodies	Artificial Surfaces	Bare Land	Transfer-Out
2000	cultivated land		1574.40	248.25	3.26	205.36	594.92	1.88	2628.08
	forest	1223.05		1479.77	0.57	132.54	165.19	3.66	3004.79
	grassland	438.50	1315.82		0.26	29.07	64.96	1.59	1850.21
	wetland	0.45	0.076	0.0099		3.69	0.079	0.00	4.31
	water bodies	97.41	74.72	20.47	5.10		9.61	0.54	207.86
	artificial surfaces	46.15	9.96	3.55	0.080	10.30		0.00	70.04
	bare land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	transfer-in	1805.56	2974.99	1752.05	9.27	380.96	834.76	7.68	7765.28

The spatial and temporal changes in land use types are mostly related to human activities and changes in natural conditions [20]. Rapid urbanization in China has led to a significant increase in built-up area, substantial reductions in cultivated land and forest coverage, degradation of grassland, and the emergence of bare land. Therefore, the implementation of policies such as the return of farmland to forest and the balancing of occupation and replenishment of arable land is of great significance in protecting the ecological environment of the Wuling Mountains area of Hunan Province and maintaining the ecological security of the region.

3.3.2. Spatiotemporal Dynamic Evolution of Ecosystem Service Value

The ecosystem service value in the Wuling Mountains area of Hunan Province exhibited a fluctuating yet overall increasing trend, as depicted in Figure 4. In 2000, 2010, and 2020, the ecosystem service values were CNY 303.88×10^9 , CNY 302.17×10^9 , and CNY 307.65×10^9 , respectively (Table 3). From 2000 to 2020, forests provided over 77% of the total ecosystem service value, making them the largest contributor. Following closely were water bodies, contributing approximately 9% of the ecosystem service value annually in the study area. The presence of water body systems, such as the Yuanshui and Zishui rivers, highlighted the prominent role of hydrology in influencing ecosystem service values, with regulating services comprising a considerable proportion, approximately 68%, of the total service value. Support services account for approximately 21%. In contrast, provisioning services and cultural services have relatively low shares, with provisioning services constituting only 5% annually, while cultural services account for merely 4%. This can be attributed to the study area not being a food-producing region and lacking significant tourism development.

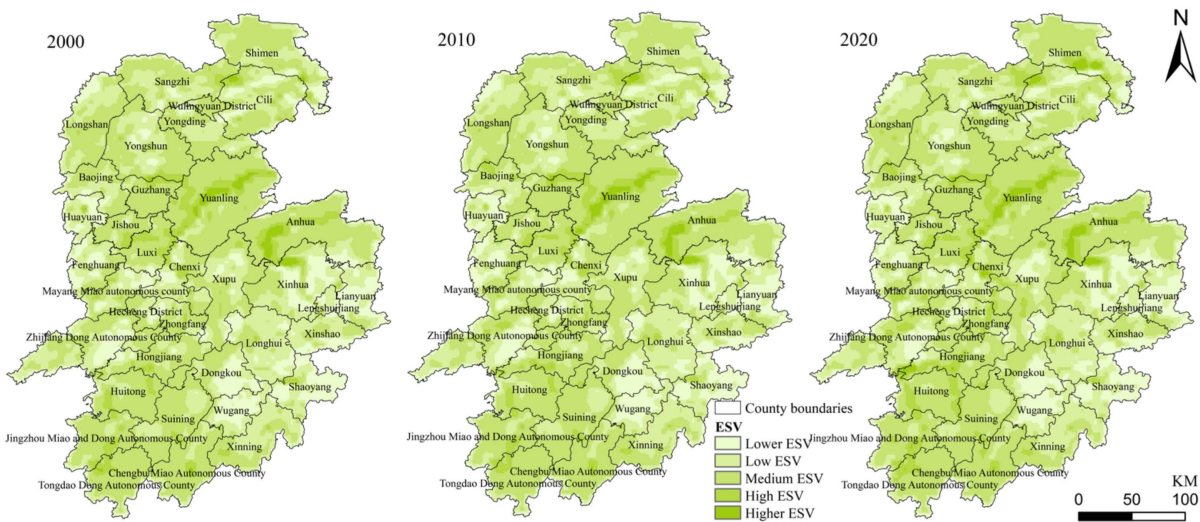


Figure 4. Spatial distribution of ESV in the Wuling Mountains area of Hunan Province.

Table 3. Ecosystem service value and proportion of different land use types.

Land Use Type	2000		2010		2020	
	Supply ($\times 10^9$ CNY)	Proportion (%)	Supply ($\times 10^9$ CNY)	Proportion (%)	Supply ($\times 10^9$ CNY)	Proportion (%)
cultivated land	19.41	6.67%	19.31	6.68%	18.71	6.35%
forest	227.55	78.20%	227.99	78.82%	227.42	77.17%
grassland	16.69	5.74%	16.80	5.81%	16.44	5.58%
wetland	0.06	0.021%	0.14	0.049%	0.11	0.038%
water bodies	27.25	9.37%	25.00	8.64%	31.96	10.85%
artificial surfaces	0.0017	0.0059%	0.19	0.0052%	0.49	0.017%
bare land	0	0	0	0	0.0018	0.00061%

Over the past two decades, the Wuling Mountains area of Hunan Province has experienced a decline in cultivated land, forest area, and grassland due to rapid urbanization. Consequently, the proportion of ecosystem service value provided by these land types has decreased. On the other hand, the area of construction land dramatically expanded, with the area of construction land in 2020 being nearly 2.9 times that in 2000, and bare land appeared. Despite these negative trends, recent efforts in Hunan Province have focused on the protection and restoration of wetlands, along with the implementation of the “never crossing a red line” policy. As a result, there was an increase in the value of the ecosystem service supply of wetland and water bodies in the Wuling Mountains area of Hunan Province by $\text{CNY } 56.81 \times 10^6$ and $\text{CNY } 4781.86 \times 10^6$, respectively.

The ecosystem service value in the study area was categorized into five grades using the natural break point method: lower ecosystem service value (lower ESV), low ecosystem service value (low ESV), medium ecosystem service value (medium ESV), high ecosystem service value (high ESV), and higher ecosystem service value (higher ESV). These values correspond to varying shades in Figure 4, which visually represent the different categories. Temporally, there has been a general decrease in the area covered by lower ESV, low ESV, and medium ESV. However, the areas of high ESV and higher ESV consistently grew, with increases of 25.28% and 42.51%, respectively (Table 4). Spatially, the Wuling Mountains area of Hunan Province showed a high degree of heterogeneity in ecosystem service values. The western, northern, and southeastern parts of the region primarily showed lower or low supply values, while the Yuanjiang, Zishui, and other water body systems predominantly showed high and higher supply values. The remaining areas of the study area fell into the medium supply value category. The region with lower ecosystem service values was concentrated in the rapidly developing areas of the study area, which had a high demand for construction land and sparse vegetation cover. This lower ecosystem service region was extensively linked to other low-value regions. Conversely, regions with high ecosystem service values experienced low anthropogenic disturbance and had well-preserved natural ecosystems, high vegetation cover, and strong support functions from water bodies.

Table 4. Change in ESV at five grades in the Wuling Mountains area of Hunan Province.

Grades	2000		2010		2020		2000–2020	
	Area (KM ²)	Proportion (%)	Area (KM ²)	Proportion (%)	Area (KM ²)	Proportion (%)	Changed Area (KM ²)	Proportion (%)
Lower ESV	14,041.49	16.34	14,207.43	16.53	13,630.69	15.86	−410.80	−2.93
Low ESV	23,447.3	27.28	23,940.39	27.86	23,240.12	27.04	−207.19	−0.88
Medium ESV	42,727.65	49.72	42,594.15	49.56	41,712.12	48.54	−1015.45	−2.38
High ESV	4635.63	5.39	4084.15	4.75	5807.37	6.76	1171.74	25.28
Higher ESV	1085.923	1.26	1111.806	1.29	1547.59	1.80	461.67	42.51

3.3.3. Spatiotemporal Dynamic Evolution of Ecological Risk

The ecological risk in the Wuling Mountains area of Hunan Province was spatially interpolated for three periods (2000, 2010, and 2020) using ordinary kriging interpolation.

The ordinary interpolation method was used to assign the ecological risk value to the center point of each evaluation unit. The ecological risk values were then classified into five levels using the natural break point method: lower ecological risk index (lower ERI), low ecological risk index (low ERI), medium ecological risk index (medium ERI), high ecological risk index (high ERI), and higher ecological risk index (higher ERI). Figure 5 illustrates the spatial distribution of ecological risk levels in the Wuling Mountains area of Hunan Province.

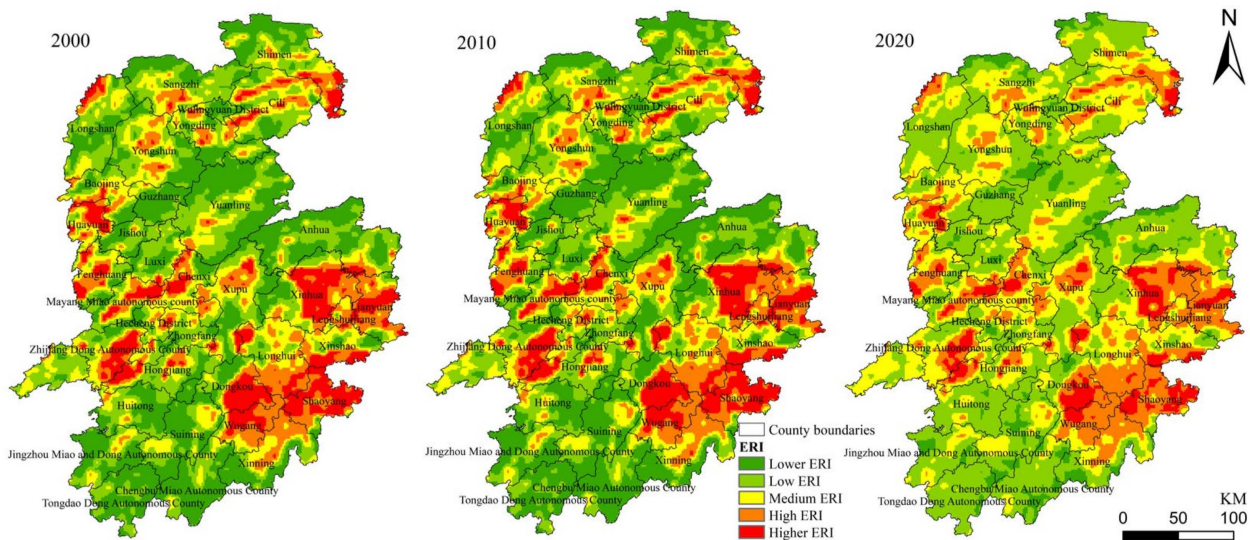


Figure 5. Distribution of ecological risk levels in the Wuling Mountains area of Hunan Province.

The ecological risk index in the region showed an overall increasing trend (Table 5). The mean ecological risk indexes for the years 2000, 2010, and 2020 were 0.0384, 0.0383, and 0.0395, respectively, with corresponding standard deviations of 0.00582, 0.00579, and 0.00427. The areas of low ERI, medium ERI, high ERI, and higher ERI expanded. Notably, the region with a medium ERI experienced the most significant growth, expanding by 1613.06 km², an increase of 11.62%. Over the span of 20 years, the area of higher ERI expanded by 624.84 km². The transition analysis revealed that the region previously classified as lower ERI primarily shifted to the category of low ERI, accounting for 74.67% of the transitions (Table 6). The higher ERI areas underwent a transition to the high ERI category, with a proportion of 33.95%. In addition, the regions classified as low ERI, medium ERI, and high ERI experienced a net inflow. A spatial analysis revealed a spatial pattern, with the southeast and west showing higher ecological risk, while the remaining areas showed comparatively lower levels of risk.

Table 5. Area change in the ERI at five grades in the Wuling Mountains area of Hunan Province.

Grade	2000		2010		2020		2000–2020	
	Area (KM ²)	Proportion (%)	Area (KM ²)	Proportion (%)	Area (KM ²)	Proportion (%)	Changed Area (KM ²)	Proportion (%)
Lower ERI	27,891.16	32.47	27,730.09	32.30	26,186.58	30.47	−1704.58	−6.11
Low ERI	22,259.45	25.92	21,314.31	24.82	21,975.13	25.57	−284.32	−1.28
Medium ERI	13,886.81	16.17	14,109.51	16.43	15,499.87	18.04	1613.06	11.62
High ERI	12,113.38	14.10	12,409.09	14.45	12,309.17	14.32	195.79	1.62
Higher ERI	9740.77	11.34	10,301.11	12.00	9967.22	11.60	624.84	2.32

Table 6. Area transition matrixes of ERI grades in the Wuling Mountains area of Hunan Province from 2000 to 2020.

	2020	Lower ERI	Low ERI	Medium ERI	High ERI	Higher ERI
2000	Lower ERI	25.04%	74.67%	0.10%	0.19%	
	Low ERI	0.13%	63.22%	36.40%	0.24%	
	Medium ERI	0.39%	2.29%	91.23%	6.09%	
	High ERI		1.06%	11.06%	87.43%	0.45%
	Higher ERI			1.24%	33.95%	64.81%

3.3.4. Dynamic Changes in Ecological Zoning

The ecosystem service value index and ecological risk index were standardized using Z score standardization, and the standardized ecosystem service value and standardized ecological risk index formed points on the composition plane, which were marked on a four-quadrant graph centered around the origin. The *x*-axis represents ecological risk, while the *y*-axis represents ecosystem service value. Consequently, the study area was divided into four ecological zones based on their ecosystem service value and ecological risk index. These zones included the high ecosystem service value–high ecological risk index zone (“High–High”), in the first quadrant; the high ecosystem service value–low ecological risk index zone (“High–Low”), situated in the second quadrant; the low ecosystem service value–low ecological risk index zone (“Low–Low”), found in the third quadrant; and the low ecosystem service value–high ecological risk index zone (“Low–High”), present in the fourth quadrant. Additionally, management measures were proposed for each zone. Figure 6 shows the spatial distribution of ecological zones in the Wuling Mountains area of Hunan Province. Table 7 shows The ESV per unit area and average ecological risk.

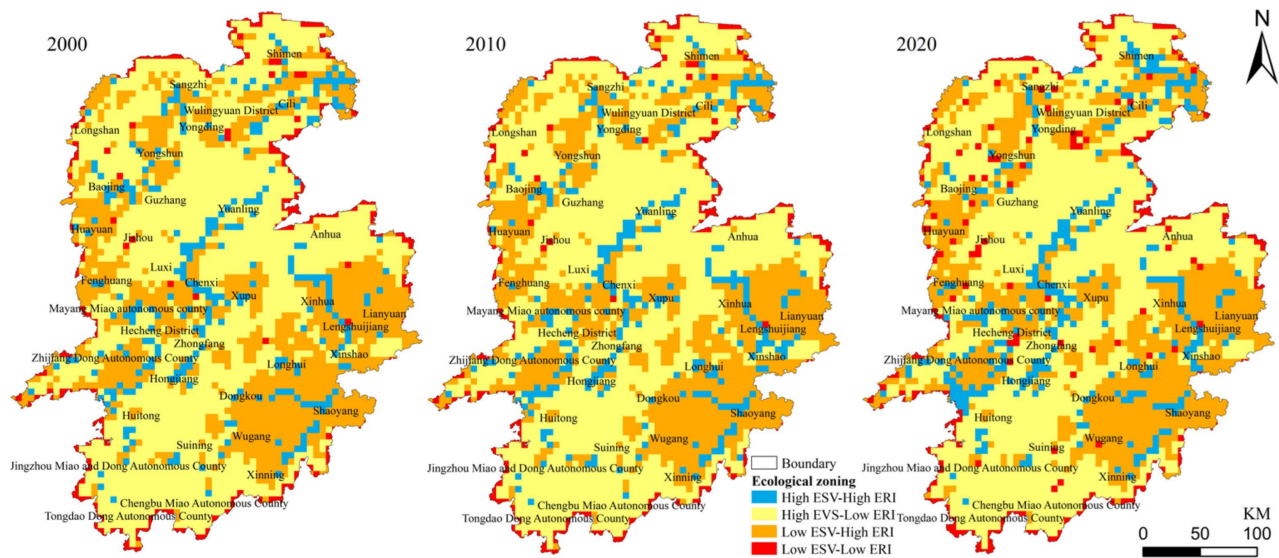


Figure 6. Spatial distribution of ecological zones in the Wuling Mountains area of Hunan Province.

Table 7. The ESV per unit area and average ecological risk.

Ecological Zones	2000		2010		2020	
	ESV Per Unit Area (CNY/km ²)	Average Ecological Risk	ESV Per Unit Area (CNY/km ²)	Average Ecological Risk	ESV Per Unit Area (CNY/km ²)	Average Ecological Risk
High–High	43.60 × 10 ⁵	0.04306	43.09 × 10 ⁵	0.04285	46.01 × 10 ⁵	0.04292
High–Low	39.46 × 10 ⁵	0.03399	39.46 × 10 ⁵	0.03396	39.29 × 10 ⁵	0.03618
Low–Low	37.64 × 10 ⁵	0.03293	37.80 × 10 ⁵	0.03279	35.68 × 10 ⁵	0.03560
Low–High	25.97 × 10 ⁵	0.04535	25.78 × 10 ⁵	0.04527	26.14 × 10 ⁵	0.04447

High Ecosystem Service Value–High Ecological Risk Zone (“High–High”): This subzone accounted for 8.62% of the total area in 2000 and 8.55% of the total area in 2010, and this proportion rose to 9.56% in 2020. The ESV per unit area in this zone was 43.60×10^5 CNY/km², 43.09×10^5 CNY/km², and 46.01×10^5 CNY/km² in 2000, 2010, and 2020, respectively, with average ecological risk indexes of 0.04306, 0.04285, and 0.04292, respectively. This subzone had considerable overlap with wetlands and cultivated land because the zone was situated along rivers. Therefore, this area was mostly covered by water bodies, wetlands, forests, and scattered grasslands.

High Ecosystem Service Value–Low Ecological Risk Zone (“High–Low”): This zone had the largest proportion of total area between the four parts, with the proportion of the total area exceeding 53% in the three periods. The ESVs per unit area in 2000, 2010, and 2020 were 39.46×10^5 CNY/km², 39.29×10^5 CNY/km², and 39.81×10^5 CNY/km², respectively, with average ERIs of 0.03399, 0.03396, and 0.03618, respectively. This zone was widely distributed, and the major land use types were forest and grassland.

Low Ecosystem Service Value–Low Ecological Risk Zone (“Low–Low”): This zone had the smallest proportion of area among the four zones. The ESV per unit area in this zone was 37.64×10^5 CNY/km², 37.80×10^5 CNY/km², and 35.68×10^5 CNY/km², with average ERI values of 0.03293, 0.03279, and 0.03560 for the three periods, respectively. This subzone was mainly distributed at the edge of the study area, and the remaining part was scattered in the central and northwestern parts of the study area. In addition, the major land use types were artificial surfaces and grassland.

Low Ecosystem Service Value–High Ecological Risk Zone (“Low–High”): The share of this zone was approximately 32%. The ESVs per unit area in this zone were 25.97×10^5 CNY/km², 25.78×10^5 CNY/km², and 26.14×10^5 CNY/km² for 2000, 2010, and 2020, respectively, and the average risk values were 0.04535, 0.04527, and 0.04447, respectively. The major land use types in this zone were cultivated land, artificial surfaces, and bare land.

3.3.5. Ecological Zoning Management

“High–High” zone: This area is an ecological control zone. This zone shows both a high ecosystem service supply value and a high ecological risk. Therefore, the key to ecological construction in the region is to control the deterioration of the regional ecological environment while maintaining the existing basic conditions of ecological security. The study area has significant overlap with the Yuanjiang, Zishui, and Lishui rivers, as cultivated land stretches along their banks. The zone is characterized by high altitude, steep slopes, abundant rainfall, and susceptibility to natural disasters, such as droughts and floods. Given these conditions, the district should prioritize ecological restoration projects, enhance the efficiency of land utilization [21], promote diversified agriculture and planting practices, strengthen river supervision, implement a grid and hierarchical system, assign concrete responsibilities, improve water body conservation projects, and enhance flood prevention and mitigation systems while ensuring the protection of the original ecological environment [22].

“High–Low” zone: This area is an ecological barrier zone. The main function of this zone in the region is to maintain the good functioning of the ecosystem and to enhance the overall ecosystem services value. This zone is predominantly covered by forests and grasslands, and it is in the core area of China’s subtropical forest system, renowned for its abundant biodiversity. Consequently, it is imperative to enhance environmental protection efforts in key ecological function areas within this zone. Measures must be taken to protect endangered wildlife through on-site conservation. Furthermore, there is a need to reinforce the management of natural forest resources and implement projects focused on preserving natural forests. Logging activities should be strictly prohibited, while initiatives for low-efficiency forest renovation and reforestation should be implemented [23]. In addition, we aim to strengthen the safeguarding of pasture resources by implementing effective grazing restrictions and addressing the practical challenges faced by local herders.

“Low–Low” zone: This area is an ecological conservation zone. The key to ecological construction in this district is to enhance the utilization of existing ecological resources and to improve the vegetation cover. In this subzone, vegetation cover is sparse, and biodiversity is limited, with a small number of plant and animal species. The available land area that could supply valuable services is also limited, and the economic foundation is weak. Therefore, it is crucial to maintain a harmonious balance between economic development and the ecological environment. It is necessary to continuously focus on constructing projects that enhance vegetation coverage, improve the quality of the ecological environment [24], and optimize land utilization.

“Low–High” zone: This area is an ecological improvement zone. The key point of ecological construction in this district is to strengthen the management of urban ecological damage and to intensify land use. This zone is characterized by frequent human activities, a developed economy, and high population density, with land for construction increasing year by year and ecological land decreasing year by year. Economic development has squeezed the ecological space, intensifying the conflict between population and land. To address these problems, the principle of “population–land coordination” must be upheld, emphasizing intensive and optimized land use. Moreover, implementing ecological compensation policies is vital to promote efficient resource utilization and enhance the management of the surrounding ecological environment [25]. Additionally, comprehensive initiatives targeting stone desertification control should be prioritized to curb its expansion.

4. Discussion

Regional geographic location and ecological resource endowment are important factors affecting the economic development of a region and influencing human well-being [26,27], while land use change can reflect the ecological environmental changes in a region over time and partially reflect the region’s potential for economic development. The ecosystem service value and ecosystem risk measurement model based on land use change, widely adopted in the literature [28–30], informs the ecological zoning method adopted in this paper. This approach evaluates ecological security by considering both positive and negative aspects, intending to guide future trade-offs between ecological enhancement and human–land relationship coordination in the study area. It provides a clear development strategy for different zones, informed by natural conditions, and outlines targeted zoning controls. Consequently, this framework aims to optimize the ecological value of the Wuling Mountains area of Hunan Province and offer new perspectives for regional ecological zoning management and conservation planning.

4.1. Analysis of Land Use Change

Land use is a factor that significantly affects the values of ecosystem services and ecological risks. Changes in land use can directly alter the changes in landscape patterns in a region and at the same time cause changes in the supply of ESV and ERI, which in turn affects the sustainability [31] of ecosystems in the region. In addition, land use reflects various human production and living activities [32,33]. Therefore, to realize green development in the region, land use restructuring is needed. The results show that during the period from 2010 to 2020, forestland accounted for more than 64% of the study area in both cases; this was followed by cropland, which accounted for approximately 26% of the total area, consistent with the results of Fanjian’s (2022) study [34]. However, both land use types were a net transfer, which can be attributed to the rapid development of urbanization in China, where the increase in construction area constantly squeezes the other land use types, as evidenced by the net increase in the areas of man-made surface and bare land. In addition, the emergence of bare land has made the changes in the ecological environment of the study area more obvious and profound. It has been suggested that desertification in Hunan Province is the result of both natural and human factors, with population growth, overgrazing, and extensive management as the main causes [35]. Therefore, to keep

the regional ecosystem functioning well, enhanced ecosystem services value, reduced ecological risk, excellent land planning, and rational land utilization are needed.

4.2. Impact of Land Use Change on Ecosystem Services Value

Ecosystems create and provide the conditions necessary for human activities, and they also reflect the health of ecosystems and influence human well-being [36,37]. The results showed that the value of ecosystem services had an upward trend. This was mainly because the study area has many woodlands and water bodies. Woodlands are a major contributor to the value of ecosystem services, which is important in maintaining ecosystem patterns, functions, and processes in the study area, broadly in line with the results obtained by Wang Yingli (2021) [38]. With the implementation of the wetland protection policy in Hunan Province, the value of ecosystem services provided by wetlands and rivers has gradually increased, with a prominent hydrological role and a large share of regulating services. However, the acceleration of urbanization and the irrational use of natural resources by humans have triggered a decline in ecosystem services provided by cultivated land and the emergence of bare land, which has created an area of low ecosystem service value in the study area. In addition, since the study area is not food-producing, tourism development is not high, so its provisioning and cultural services accounted for a relatively low percentage. Therefore, to improve the value of ecosystem services, we should select low ecosystem service value areas as entry points, reduce the rate of desertification, change the mode of operation, and rationalize land use.

4.3. Analysis of Changes in Ecological Risk

Ecological risk assessment measures the negative impacts on ecological processes and landscape patterns and is a prerequisite for effective ecological risk prevention and control. The results showed that the overall ecological risk in the study area was increasing. Changes in ecological risk tend to be strongly correlated with human activities [33,39,40]. The ecological risk index tends to be higher in areas with frequent human activities and poor natural conditions, such as town centers, development and construction areas, and desert zones, while areas with high altitudes and dense water sources generally show a low ecological risk index. In the study area, Lianyuan City, Xinhua County, Shaoyang County, Wugang City, Fenghuang County, Dongkou City, Shimen County, and other counties and cities, with rapid economic development and dense populations, were the major high-risk aggregation areas. Higher altitude areas, such as Sangzhi County and Chengbu Miao Autonomous County, and counties and cities with relatively backward economic development, such as Jingzhou Miao Autonomous County, Dong Autonomous County of Tongdong, and Guzhang County, were the major low-risk aggregation areas. Some studies have suggested that there is a link between ecological risk and ecosystem service value [41–43], so we may be able to start from this perspective on how to reduce ecological risk in the region by considering the linkage between the ecosystem service value of the region and ecological risk; then, we can adopt different measures based on the different linkage effects.

4.4. Discussion of Ecological Zoning and Management

Ecological zoning can break the tradition of dividing on the basis of administrative boundaries, and it can flexibly adopt targeted zoning bases for different characteristics and areas, combined with management needs, to meet differentiated management needs. The results show that the four types of zoning in the study area are relatively stable with a small degree of change, but the zoning is polarized. The combination of the ecological barrier zone accounts for more than 85%, while the ecological improvement zone and ecological conservation zone account for less than 15%. Based on this, we propose targeted zoning management recommendations based on the plan. The ecological control zone is characterized by high altitude, steep slopes, abundant rainfall, droughts and floods, and other natural disasters, so the region should continue to implement ecological restoration

projects under the condition of protecting the original ecological environment. The ecological barrier zone is dominated by forest and grassland, is rich in biodiversity, and has a high proportion of forests and grasslands. Thus, it is necessary to continue to strengthen the key ecological functional areas of environmental protection and fully implement natural forest resource management. The ecological conservation zone vegetation cover is scarce, and land resources are tight, with backward economic development; thus, it is necessary to continuously focus on developing projects that enhance vegetation coverage, improve the quality of the ecological environment, and optimize land utilization. The ecological control zone is characterized by tense conflicts between people and land, a high population density, and a small ecological space; therefore, this zone must insist on the implementation of the policy of ecological compensation to force the efficient use of resource elements, strengthen the management of the surrounding ecological environment, and prohibit excessive development.

In this study, the value of ecosystem services, the spatial and temporal evolution of landscape ecological risk, and the identification of ecospatial zoning in the Wuling Mountains area of Hunan Province were studied, which provided a new way of thinking about ecological functional zoning and established a framework of ecological zoning based on “value–risk”. However, due to space limitations, we did not analyze the relationship between ecosystem service value and ecological risk, the influence mechanism, and the spatial spillover effect of ecosystems inside and outside the study area. In addition, the framework of “value–risk” does not include economic indicators. As we read the relevant literature, we found that land use directly affects the regional ecological environment as well as regional economic development, so land use may be the key element between ecological environment protection and economic development.

Therefore, we will try to take the ecosystem services value as the end point of ecological risk assessment in the future and expand the “value–risk–economy” framework by using coupled coordination analysis based on the grid method. This approach should help identify the link between ecosystems and socio-economic systems, and the framework can be used to analyze the degree of coordination between regional ecological environment and economic development, as well as to propose more socio-economically adaptable environmental protection strategies. In addition, in exploring the relationship between ecosystem service value and ecological risk, the influence mechanism and the spatial spillover effect of ecosystems inside and outside the study area are also directions for future research.

5. Conclusions

Based on land use change, we constructed a model for measuring the values of ecosystem services and ecological risk. Furthermore, we established four ecological zones and proposed a unique environmental protection recommendation for each area. Similarly, the framework also applies to other developing countries. It provides a new analytical framework for other developing countries to solve the problem of ecological environment protection, which should help them formulate environmental protection strategies, build an overall regional security barrier, and construct an overall ecological security pattern. In addition, it also pays more attention to vulnerable groups, and it can enable people worldwide to enjoy the benefits provided by the ecological environment equally and simultaneously.

- (1) Forestland has been the dominant land use type in the study area, followed by cropland. As far as land use changes are concerned, the absolute change area of land use types was large, and the relative change area was small. Among them, cropland, forestland, and grassland were net transfer-out land use types, while wetland, water bodies, man-made surfaces, and bare land were net transfer-out land use types. Notably, bare land was the most recent land use type to appear.
- (2) The value of ecosystem services shows an upward trend. Forestland is the main contributor to ecosystem service value. The spatial heterogeneity of ecosystem service

value is obvious, with river and mountain areas having mostly high ecosystem service value areas, cropland and bare land having a high overlap with low ecosystem service value areas, and medium ecosystem service value areas being interspersed with other levels of ecosystem service value areas.

- (3) The ecological risk is increasing, showing a spatial pattern of high ecological risk in the southeast and west and relatively low ecological risk in the remaining region. High ecological risks were mainly concentrated in several counties and cities in the study area that have faster economic development and are densely populated, such as Lianyuan City, Xinhua County, Shaoyang County, Wugang City, Fenghuang County, Dongkou City, and Shimen County.
- (4) The study area was divided into an ecological improvement zone, an ecological barrier zone, an ecological conservation zone, and an ecological control zone. The degree of change in the four kinds of zoning in the study area was small and in a relatively stable state. The zoning also showed polarization, with the ecological barrier zone and the ecological control zone accounting for more than 85% of the total area. Finally, targeted strategies are proposed for different sub-regions based overall.

Ecological zoning based on the value of ecosystem services and ecological risks characterizes the ecological security situation from both positive and negative aspects, clarifies the development orientation of different zones, and helps formulate more focused and refined regional environmental protection strategies. In the future, we will try to expand the framework and find a direct link between the ecological environment and economic development, to develop more socio-economically adaptable environmental protection strategies, and to realize the unity of ecological and economic values.

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