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Landscape Ecological Risk Assessment Based on LUCC—A Case Study of Chaoyang County, China

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Abstract: The ecological environment is suffering from great human disturbance. Scientific assessment of landscape ecological risks can provide scientific guidance for land use management. This study focused on Chaoyang County in China, used ecological risk assessment methods to characterize the impact of land use/land cover (LUCC) change, and revealed the risk aggregation pattern with the help of spatial autocorrelation analysis. The results showed that ecological risk was increased from 2000 to 2010 but decreased from 2010 to 2018. The ecological risk of the Daling River and Xiaoling River basin was at a relatively high level, and low in the northwest and southeast of the study which covered by forest land. Occupying cultivated land for built-up and large-scale deforestation were two of the main factors to contribute to the increase of ecological risk. The distribution of High-High (HH) and Low-Low (LL) risk agglomeration areas was basically the same as risk levels, but the scope is smaller and more precise. Thus, HH and LH risk agglomeration area should be paid more attention to prevent the adverse impact of adjacent areas. Our study gave a novel perspective to investigate the pattern of ecological risk in order for government managers to identify key risk areas.

Keywords: land use/land cover; ecological risk; spatial autocorrelation

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1. Introduction

Global warming is unprecedented challenge mankind faces today and posed a serious threat to the sustainable development of human society. The Intergovernmental Panel on Climate Change (IPCC) proposed that achieving the 1.5 °C temperature control target was expected to avoid the irreversible negative effects of climate change on human society and natural ecosystems, and this required the joint efforts of all countries to reach net zero CO_2 emissions by 2050 [1]. China proposed that achieve peak carbon dioxide emissions by 2030 and carbon neutrality by 2060 at the 75th General Assembly of the United Nations. Several studies had shown that if China were to achieve the goal of achieving carbon neutrality before 2060, this would relieve global warming projections by around 0.2 to 0.3 °C [2]. Land use/land cover change has an effect on the increase of global atmospheric carbon dioxide content, second to the effects of burning fossil fuels [3]. Among them, the carbon sink function of forests plays an important role in the entire terrestrial ecosystem, accounting for about 2/3 of the entire terrestrial ecosystem [4]. Therefore, reasonable land use is one of the effective ways to alleviate this problem. However, the demand for land has surged since the 21st century [5], and land use activities have become more intense with the rapid economic development. Large-scale land development and deforestation have led to the imbalance of the internal structure and function of the natural ecosystem [6,7], which inevitably leads to a series of ecological and environmental problems [8], such as soil erosion [9], land desertification [10], and biodiversity loss. These problems could cause an increase in ecological risk [11]. In turn, the increased ecological risk constrains the rational use of land, which creates an undesirable cycle.

Risk assessment originated in the 1980s, which was initially limited to the field of human health assessment. In the following years, Environmental Impact Assessment (EIA) was proposed to investigate the ecological impact of chemical pollutants with toxicological analysis methods [12]. In 1983, The risk assessment framework centered on human health and safety was proposed by the National Research Council (NRC) of the United States. And then a series of technical guidelines were issued by the U.S. EPA, which basically formed the scientific system of risk assessment. Since the 1990s, the focus of risk assessment gradually shifted to ecological risk assessment, and risk factors and receptors were gradually diversified [13], which symbolizes a relatively complete ecological risk assessment system initially formed. From the end of the 20th century to the beginning of the 21st century, researchers paid more attention to the connection between ecological risk assessment and landscape ecology and then established the abovementioned coupling relationship. On this basis, landscape ecological risk assessment was formed. Landscape ecological risk assessment aims to evaluate the possibility and extent of various adverse disturbances caused by human activities/natural factors changes to the ecosystem [14,15]. At present, two main evaluation methods, i.e., of risk source-sink [16,17] and landscape pattern [18,19], were used in landscape ecological risk assessment. Landscape ecological risk evaluation pays more attention to the impact of land use/land cover change based on landscape pattern which is obviously different previous ecological risk evaluations. Several studies have shown that there is a close ecological relationship between land use and ecological risk. And the landscape pattern can quantitatively reflect land use/land cover change [20]. The risk receptor of this method is the ecosystem itself that carries the landscape pattern, instead of its elements. And the risk source was the risk effect caused by the deviation of the existing landscape pattern from the optimal pattern, rather than a specific and well-defined source of the disturbance. Therefore, the spatiotemporal heterogeneity of landscape ecological risk and the influence of existing landscape patterns on risk is the focus of this method [21], and the role of ecological theory in this process has been paid more attention. However, few studies applied the spatial autocorrelation analysis to explore the agglomeration regularity of landscape ecological risk. In fact, spatial autocorrelation analysis can help us to effectively highlight the spatial pattern of ecological risk distribution, and rapidly identify high-risk areas that need to be focused on in environmental management. Otherwise, the existing research areas of landscape ecological risk assessment were mainly concentrated in ecologically fragile areas such as industrial and mining areas [21], river basins [22], nature reserves [23], and large-scale urban areas [14].

The Northeast region of China has experienced large-scale and dramatic land use changes in a short period [24]. In addition, the area of Northeastern forests is the largest in China [25], accounting for 1/3 of the country's forest area. Negative land use such as deforestation, destroying forests for reclaiming wasteland and disorderly expansion of construction land not only threaten ecological security, but also caused damage to carbon sequestration capacity of forests. Chaoyang County as a typical county-level administrative district of Northeast China was selected in this study. On the basis of the land use data in 2000, 2010, and 2018, the spatiotemporal distribution of landscape ecological risk was analyzed. We aimed to scientifically assess the ecological risk of the landscape based on LUCC and provide experience for county-level administrative units to prevent and resolve ecological risks which could give some help to achieve the goal of carbon neutrality. The specific objectives of this study are: (1) Analyze the spatiotemporal characteristics of land use change in the study area from 2000 to 2018; (2) Establish the landscape ecological risk Index (ERI) assessment model to explore the regular distribution of landscape ecological risk; (3) Identify key risk areas through spatial autocorrelation analysis.

2. Materials and Methods

2.1. Study Area

Chaoyang County, lying between 36°55′ N and 38°22′ N and 96°15′ E and 98°15′ E, is located in the west of Liaoning Province, China, with a total area of 425,350 hm^2 (Figure 1). It belongs to the temperate continental monsoon climate zone, with an annual average temperature of 8.3~8.9 °C (http://www.cyx.gov.cn (accessed on 18 July 2021)) [26]. The terrain of Chaoyang County presents an appearance of high in the northwest and low in the southeast, with an average altitude of 197 m. The Daling River and Xiaoling River flow from southwest to northeast. Forest land is the main land-use type, and the area accounts for more than 40% of the total area, which is far exceeding the national forest coverage. The population in the study area is dominated by the agricultural population, accounting for 94.2%. Thus, Chaoyang County is a typical agricultural county with the area of cultivated land accounting for 30%.

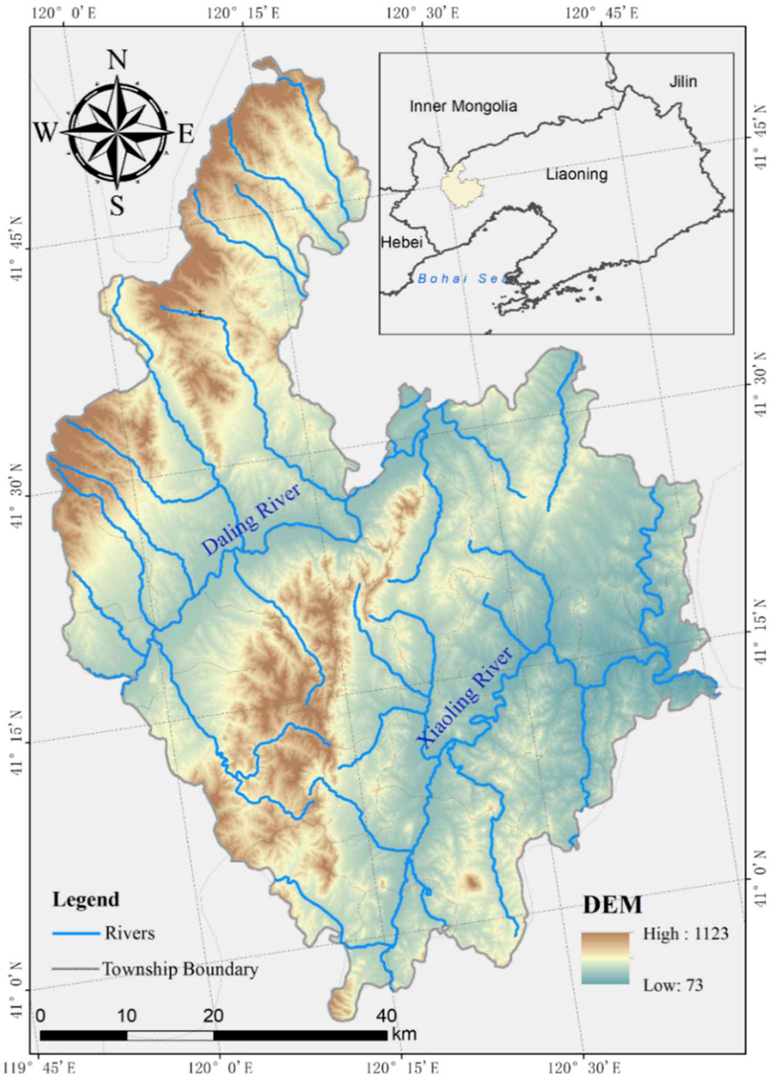


Figure 1. Study Area of Chaoyang County.

2.2. Data Collection and Processing

The land use/land cover dataset (30 m resolution, raster, 2000, 2010, 2018) was provided by Data Center for Resources and Environmental Sciences Chinese Academy of Science (RESDC) (http://www.resdc.cn (accessed on 18 July 2021)) [27–30] Land-use data for 2000 and 2010 were interpreted from Landsat TM/ETM remote sensing image data, and the date for 2018 is from Landsat 8 remote sensing image data. It has been verified by field investigation points random sampling inspection, interpretation accuracy reached 95.58%; By random sampling inspection check line, interpretation accuracy reached 95.72% [31]. The database is the most authoritative remote sensing monitoring data product of land use in China [32]. The land-use types were reclassified as six categories by using ArcGIS 10.2: cultivated land, forest land, grassland, water area, built-up land and unused land based on land resources, and land use attributes. DEM image of ground elevation (30 m resolution) was downloaded from Geospatial Date Cloud of the Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn (accessed on 18 July 2021)) [33]. The slope data was calculated with DEM with the help of ArcGIS 10.2. Water system data (shapefile) was provided by National Catalogue Service for Geographic Information (https://www.webmap.cn (accessed on 18 July 2021)) [34]. The landscape pattern indexes, such as patch number, average patch area, etc., were calculated through FRAGSTATS which is a software program designed to compute a wide variety of landscape metrics for categorical map patterns.

2.3. Methods

2.3.1. Land Use Transfer Matrix

The land use transfer matrix was an important method to analyze structural changes in land use, which could reveal the transformation direction and sources of different land-use types in a certain period [35]. In addition, this method was also applied in transfer analysis of ecological risk in this study, and help us determine specific trends in landscape ecological risk change. The internal connection between land-use change and ecological risk change can be revealed more accurately. A two-dimensional matrix was widely used, and its manifestation is as follows:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \ldots & S_{1n} \\ S_{21} & S_{22} & \ldots & S_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & \ldots & S_{nn} \end{bmatrix} (i,\ j\ =\ 1,\ 2,\ \ldots,\ n) \tag{1}$$

where S_{ij} is the area of land type i converted to land type j; n is the number of land use types.

2.3.2. Landscape Ecological Risk Index

- Determine the risk evaluation unit

Landscape ecology suggested that landscape patch size should be 2–5 times the average patch area [36]. The average patch size in the study area was 0.8218 km^2. Based on the actual situation of the study area and other previous research experiences [37], the equal interval sampling method (1.5 km × 1.5 km) was used to divide the study area into 2078 ecological risk assessment units. The ERI was calculated in each assessment unit, and the results were assigned to the central point of the assessment units.

- The ERI assessment model

ERI was constructed by the composition of different land-use types in each evaluation unit and landscape ecological risk index, which reflects the relationship between landscape patterns and ecological risk [38]. The formula is as follow [39]:

$$ERI_i = \sum\nolimits_{i=1}^{N} \frac{A_{ki}}{A_k} R_i \tag{2}$$

$$R_i = \sqrt{U_i \cdot F_i} \tag{3}$$

where ERI is the ecological risk index of each ecological risk assessment unit; A_{ki} is the area of landscape i in the area k; A_k is the area of the kth evaluation unit; R_i is the loss index [40] of land type i; U_i is the landscape disturbance index of land type i; F_i is the vulnerability index of land type i; N is the number of landscape types.

a. The landscape disturbance index U_i

The landscape disturbance index was used to measure the ability to resist the disturbance of external factors, especially human activity. The formula is as follow:

$$U_i = aC_i + bS_i + cD_i \tag{4}$$

where C_i is the landscape fragmentation of landscape i; S_i is the landscape isolation of landscape i; D_i is the landscape dominance index of landscape i; a, b, c are the weights of the three, based on previous studies [41,42] and actual situation of the study area: assign value a equal to 0.5, b equal to 0.3, c equal to 0.2.

$$C_i = \frac{n_i}{A_i} \tag{5}$$

$$S_i = \frac{1}{2}\sqrt{\frac{n_i}{A}} \cdot \frac{A}{A_i} \tag{6}$$

$$D_i = \frac{(Q_i + M_i) + 2L_i}{4} \tag{7}$$

Among them, n_i is the number of patches of landscape type i; A_i is the total area of landscape type i; A is the total landscape area of the study area; Q_i is the ratio of the landscape i area to the total area of the study area; M_i is the number of patches of landscape i divided by the number of total patches; L_i is the ratio of the number of evaluation units that the landscape i appearing to the total number of evaluation units.

b. The landscape vulnerability index F_i

The landscape vulnerability index can reflect the sensitivity of different land-use types to artificial or natural disturbance responses. Judged from previous studies [18,43] and the situation of the study area, the Delphi Method was adopted to classify the landscape vulnerability into 6 levels: 6 for unused land, 5 for water body, 4 for cultivated land, 3 for grassland, 2 for forest land, 1 for built-up land. And the landscape vulnerability index was obtained after normalization.

2.3.3. Spatial Autocorrelation Analysis

Global spatial autocorrelation can present the agglomeration characteristics of spatial variables in the total study area [44,45] and was often represented by the Global Moran's I. Global Moran's I range from −1 to 1. Assuming the absolute value is more approaching 1, it means it has a stronger autocorrelation. In this study, the Global Moran's I was used to characterize the relationships between ecological risks in space. The formula is as follows:

$$I_g = \frac{m}{\Sigma_i \Sigma_j w_{ij}} + \frac{\Sigma_i \Sigma_j w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\Sigma_i (x_i - \overline{x})^2} \tag{8}$$

where x_i is the observed value; w_{ij} is a spatial weight matrix, which is a symmetric matrix of $m \times m$, m is the number of rows or columns of the symmetric matrix of $m \times m$. When the spatial elements are adjacent, w_{ij} is equal to 1; when non-adjacent, w_{ij} is equal to 0.

Local spatial autocorrelation can effectively reflect the spatial variables' distribution state of local heterogeneity [46,47] and was often represented by Local Moran's I. In this study, Local Moran's I was used to reflect the correlation between the landscape ecological risk of each evaluation unit in the study area. The formula is as follows:

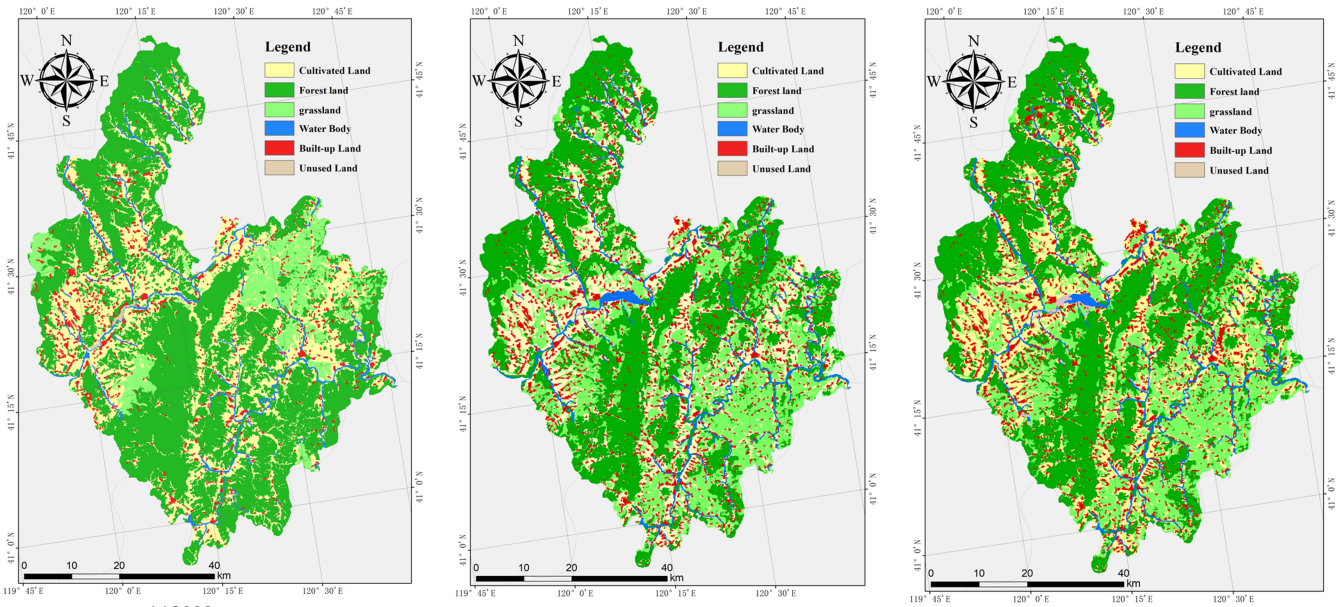
$$I_l = \frac{(x_i - \overline{x}) \cdot \sum_{j=1}^{m} w_{ij}(x_j - \overline{x})}{\sum_{1=1}^{n}(x_i - \overline{x})^2} \tag{9}$$

The meaning of each symbol is the same as that of Formula (8).

3. Results

3.1. Spatiotemporal Characteristics of Land Use/Land Cover Change

The spatial distribution maps of land use/land cover in Chaoyang County from 2000 to 2018 are shown in Figure 2. The area and proportion of each land-use type are shown in Table 1. From 2000 to 2018, forest land and cultivated land were the dominant land use types, accounted for more than 40% and 30%, respectively.



(a)2000 (b)2010 (c)2018

Figure 2. Land use/land cover in Chaoyang County in (**a**) 2000, (**b**) 2010, (**c**) 2018.

Table 1. Land use type area and proportion in 2000, 2010 and 2018.

Year		Cultivated Land	Forest Land	Grassland	Water Body	Built-Up Land	Unused Land
2000	Area (hm^2)	165,021.30	207,844.60	29,719.98	7933.23	11,567.34	513.36
	Area (%)	39.05	49.18	7.03	1.88	2.74	0.12
2010	Area (hm^2)	140,370.10	173,192.80	74,384.82	12,385.08	22,082.49	184.50
	Area (%)	33.22	40.98	17.6	2.93	5.23	0.04
2018	Area (hm^2)	139,998.40	172,447.60	73,951.47	11,772.99	23,510.16	913.86
	Area (%)	33.13	40.81	17.5	2.79	5.56	0.22

In 2000, the forest land was mainly distributed in the northwest and south of the study area, covering an area of 207,844.6 hm^2, which was up to 49.18%. From 2000 to 2018, the area of forest land continued to decline, a decrease of 8.37%, which was mainly manifested in the decline of forest areas in the southeast. The awareness of environmental protection in the region was weak during this period, and indiscriminate logging was serious, and the logged arable land was either reclaimed as cultivated land or degraded into grassland. The cultivated land area was 165,021.3 hm^2, accounting for 39.05%. It was mainly distributed in the relatively flat mountain basin of the Daling River and Xiaoling River, with a cumulative decrease of 5.92% in 18 years. The cultivated land was reduced dispersedly with a wide range; The grassland distribution was concentrated in 2000, mainly in the east of the study area and western small-scale, accounted for only 7.03%. In the past 18 years, the area of grassland has increased significantly, with an increase of up to 150%. The increased grassland is mainly distributed in the west and southeast of the study area. The area of built-up land was only 11,567.34 hm^2 in 2000, occupied to 2.74%. Since Chaoyang County is a typical "county without city" administrative region in China, it shares an administrative center with Chaoyang City, so most of the built-up lands were rural settlements. The distribution of built-up land was scattered in the Daling River and Xiaoling River basin, especially most densely distributed in the Daling River basin in the west of the study area. In the past 18 years, rural settlements have been expanded outwards on the original basis, gradually showed a trend of along the river and road connections, but it has not yet formed a large residential agglomeration phenomenon. The area ratio increased from 2.74% in 2000 to 5.56% in 2018. The area of the water body increased firstly and then decreased, mainly reflected in the increase or decrease of the pond reservoir along the river and the shrinkage of the riverbank. Unused land is scattered along the trunk stream of the Daling River, with an area of only 0.12%. It decreased firstly and then increased in 18 years and was the land use type with the largest change during the study period. The change of land use was more dramatic in the decade during 2000–2010 and slowed down in the eight years during 2010–2018.

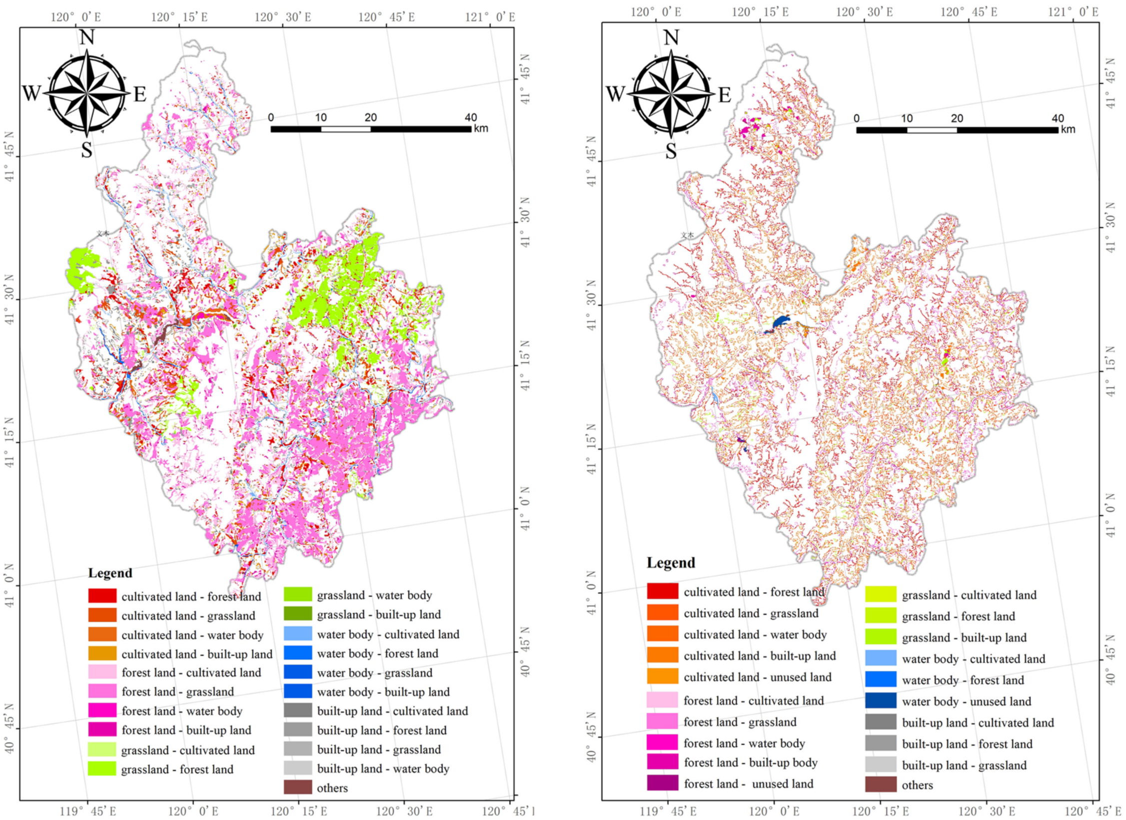
The land-use transfer matrix from 2000 to 2010 and 2010 to 2018 are shown in Tables 2 and 3, respectively. And the expression of the spatiotemporal transfer of land use types is shown in Figure 3. The land use transfer in 2000–2010 was large-scale and a large area of concentrated transfer occurred. In this period, the most significant change was the conversion of forest land to grassland, and the conversion area reached 46,516.41 hm^2, mainly occurred in the southeast. The conversion of forest land to cultivated land Scattered occurred in the entire study area, which was manifested by the expansion of the original cultivated land edge, and the conversion area reached 26,569.35 hm^2. Therefore, the largest area transferred out land use type was forest land. The land-use type with the second-largest transfer area was cultivated land, and the main transfer target was forest land, grassland, and other ecological land. 24,934.05 hm^2 and 18,014.49 hm^2 of cultivated land were converted to forest land and grassland, respectively. It mainly occurred in the area bordered by cultivated land and forest land in the Daling River and Xiaoling River basin. Built-up land was mainly expanded by occupying cultivated land, with 10,695.15 hm^2 of cultivated land converted to built-up land. The conversion of cultivated land to built-up land mainly occurred in densely constructed areas in the Daling River and Xiaoling River basin. Another noteworthy phenomenon was that a large area of grassland in the eastern was converted to forest land. Large-scale afforestation, deforestation, and land reclamation co-existed during this period. From 2010 to 2018, different degrees of transfer among various types of land still existed in the entire study area, but the intensity of transfer has been greatly weakened. This reflected the small-scale adjustment of the land use structure in the region.

Table 2. Land use transfer matrix from 2000 to 2010 (hm^2).

Land Use Types		**Area of Land in 2010/hm^2**					
		Cultivated Land	**Forest Land**	**Grassland**	**Water Body**	**Built-Up Land**	**Unused Land**
Area of land in 2000/hm^2	cultivated land	106,398.7	24,934.05	18,014.49	4861.53	10,695.15	117.36
	forest land	26,569.35	129,520.7	46,516.41	1282.05	3895.47	60.57
	grassland	3422.61	16,908.93	8675.46	168.03	540.54	4.41
	water body	1050.57	701.37	311.67	5782.14	86.49	0.99
	built-up land	2514.42	1117.98	863.64	205.74	6864.39	1.17
	unused land	414.45	9.72	3.15	85.59	0.45	0

Table 3. Land use transfer matrix from 2010 to 2018 (hm^2).

Land Use Types		Area of Land in 2010/hm^2					
		Cultivated Land	Forest Land	Grassland	Water Body	Built-Up Land	Unused Land
Area of land in 2010/hm^2	cultivated land	137,318.2	935.55	710.64	219.78	1032.21	153.63
	forest land	1113.39	170,904.8	277.65	106.38	724.14	61.83
	grassland	673.65	366.03	72,812.25	32.58	425.52	74.43
	water body	335.52	112.41	41.13	11,403.27	63.18	429.39
	built-up land	550.62	127.44	109.08	10.89	21,265.11	19.26
	unused land	7.02	1.35	0.72	0.09	0	175.32



(a)2000 - 2010 (b)2010 - 2018

Figure 3. Land use transfer in Chaoyang County in (**a**) 2000–2010, (**b**) 2010–2018.

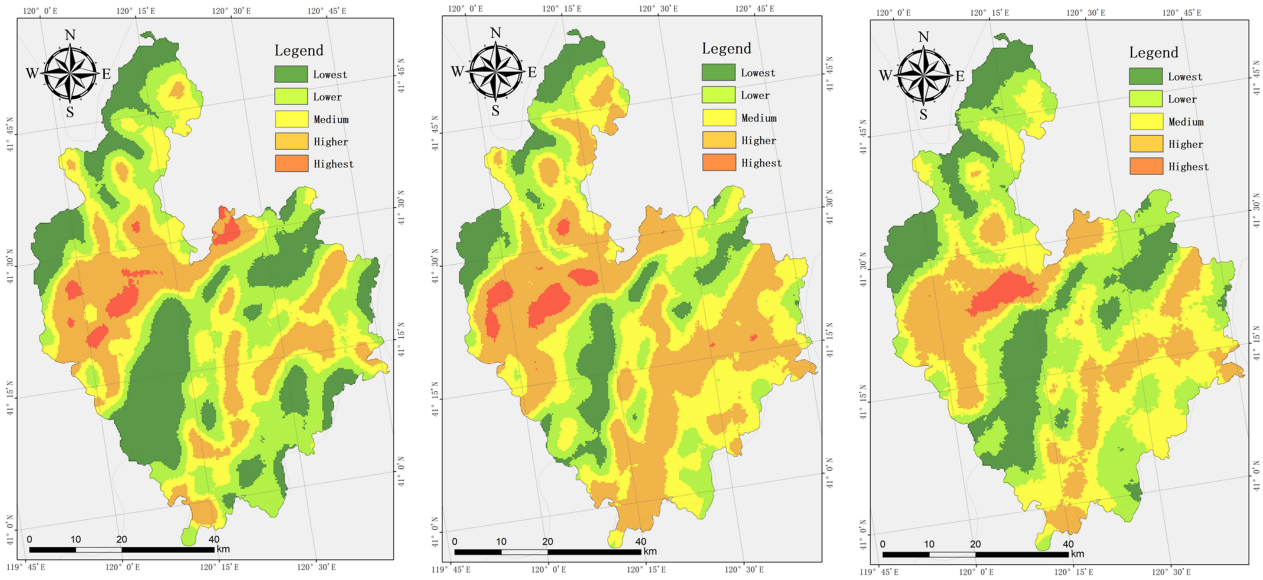
3.2. Spatiotemporal Changes of Landscape Ecological Risk Analysis

In Chaoyang Country, the landscape ecological risk was divided into five levels with the help of the natural break point method [48], as shown in Table 4.

Table 4. Ecological risk classification.

Risk Level	Lowest Risk	Lower Risk	Medium Risk	Higher Risk	Highest Risk
ERI	<0.1267	0.1267–0.1367	0.1367–0.1464	0.1464–0.1642	>0.1642

The ecological risks in the study areas were distributed at interval zonal distribution from northwest to southeast (Figure 4). Lowest risk areas and lower risk areas were mainly distributed in the northwest, southeast and middle of the area. The common feature of the areas was that they were mostly covered by forests. Due to the high terrain, it was less affected by human activities, and its ecosystem was in a higher stable state with a relatively high level of biodiversity. Higher risk areas and highest risk areas were mainly distributed in the Daling River and Xiaoling River basin. These areas were suitable for human production and living due to their natural conditions. Cultivated land was the dominant landscape of the area, and built-up land was densely distributed among them. The landscape fragmentation degree was at a relatively high level caused by human-induced. Medium risk areas were mainly distributed in the transition zone between higher risk areas and lower risk areas.



(a)2000 (b)2010 (c)2018

Figure 4. Landscape ecological risk level distribution of Chaoyang County in (**a**) 2000, (**b**) 2010, (**c**) 2018.

From the perspective of temporal changes in landscape ecological risk, the ecological risk increased from 2000 to 2010 and decreased from 2010 to 2018 (Figure 5). medium risk and lower risk areas accounted for the largest proportion in the study area, up to 60%. Higher risk and lowest risk areas were followed, and the highest risk areas were the least. From 2000 to 2010, The lower and lowest risk areas decreased by 8.49% and 13.5%, respectively. And the higher risk areas rapidly increased by 14.64%. The combined effect was an increase in the ERI in this period. From 2010 to 2018, the higher risk areas decreased by 15.76%. The proportion of lower and lowest risk areas increased by 16.92%.

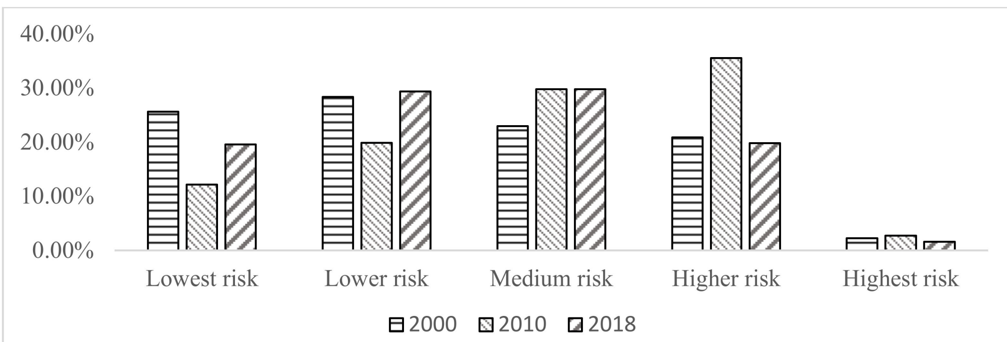


Figure 5. Proportion of different landscape ecological risk area of Chaoyang County.

From the perspective of spatial change in landscape ecological risk, the landscape ecological risk levels increased significantly before 2010 but declined after 2010 (Figure 6). From 2000 to 2010, the main change of risk levels was increased by one or two levels. The most obvious change was distributed in the southwest of the study area due to the deforestation of forest land into grassland. And the southwest of the study also had a significant level increase where sporadically increased an amount of built-up land and aggravated landscape fragmentation. The ecological risk level in the northern part of the study area has also increased, mainly due to the degradation of forest land and the expansion of built-up land. The ecological environment is showing a deteriorating trend in this period. But from 2010 to 2018, this trend was reversed. The main change of risk levels is decreased by one level in most of the total area. Residents were gradually conscious of the significance of environment conservation, and the land use types conversion was weakened. Simultaneously, the landscape fragmentation was greatly reduced.

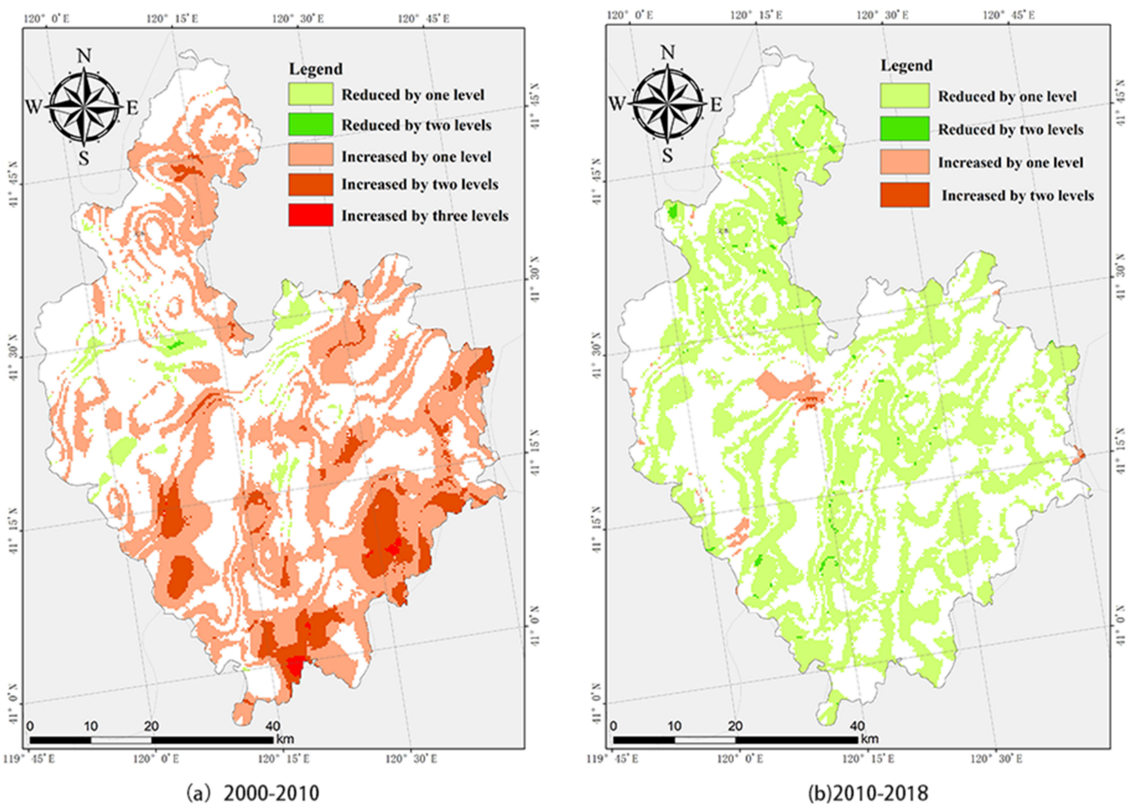


Figure 6. Changes in landscape ecological risk levels in Chaoyang County in (**a**) 2000–2010, (**b**) 2010–2018.

3.3. Spatial Autocorrelation Analysis

Moran's I was used to describe global spatial autocorrelation of the ecological risk in the study area. The values of Moran's I index in 2000, 2010, and 2018 were 0.565, 0.526, and 0.575, respectively, indicating that the landscape ecological risks had a significant agglomeration effect in the 18 years. That is to say, areas in high risks values have high risk values in surrounding areas, areas in low risks values have low risk values in surrounding areas. The Moran's I revealed a declining trend from 2000 to 2010 and an increasing trend from 2010 to 2018. This implied that the spatial aggregation of ecological risk was gradually weakened from 2000 to 2010 and enhanced slightly from 2010 to 2018.

The LISA cluster map of the landscape ecological risk index was used to express the local spatial autocorrelation (Figure 7). Four types of significant autocorrelations "High-High" (HH), "Low-Low" (LL), "Low-High" (LH), and "High-Low" (HL) have appeared in the study area. The distribution of High-High (HH) and Low-Low (LL) risk agglomeration areas was basically the same as risk levels, but the scope is smaller and more precise. The HH risk agglomeration risk areas accounted for the total number of samples in the total study area 17.6%, 16.8%, 17.3% in 2000, 2010, 2018, respectively. The result showed a trend of decreasing first and then increasing. And the HH risk agglomeration areas are primarily distributed along the Daling River and the Xiaoling River basin. The ecological environment of this area needs more attention, and without related risk management measures, it could be worse. The LL region accounted for 15.2%, 16.4%, 17.4%, respectively, which showed an increasing trend, and mainly intensively located in the forests of the Southwest and Northern. It is noteworthy that LH risk agglomeration risk areas appeared southwest and southeast of the study area. There are mutual influences between adjacent ecological risk areas. Thus, the possibility of a sudden increase in ecological risk in this area should be noticed. HL risk agglomeration risk area appeared around HH risk agglomeration of the Daling River basin, which a send us a good signal: to properly guide the ecological environment may improve in this area.

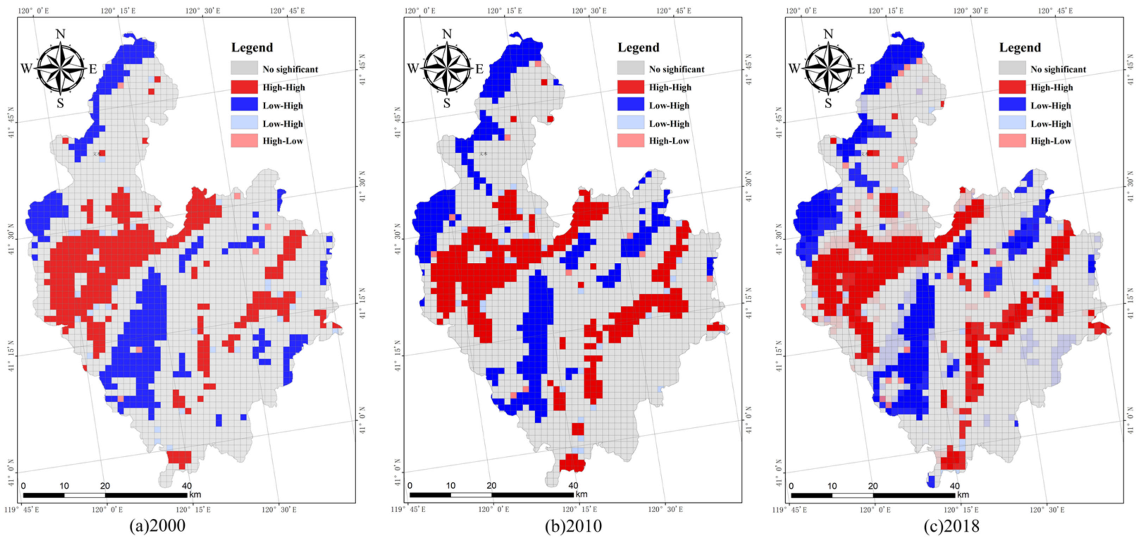


Figure 7. Local autocorrelation index of landscape ecological risk in Chaoyang County in (**a**) 2000, (**b**) 2010, (**c**) 2018.

4. Discussion

4.1. Effects of Land Use Changes on Ecological Risk

The policy is a factor that affects changes in ecological risks. The "Grain for Green" project in China is a major measure to use land resources rationally and improve the ecological environment [49]. Especially, it aimed to prevent soil erosion in the high-slope cultivated land region. Grain for green project was fully launched in 2002 [50,51]. In Figure 8, the transfer of cultivated land to forest land and grassland in Chaoyang County was mainly concentrated in areas with a slope of 6–25° near the Daling River and Xiaoling River which strengthen the stability of ecosystems to a certain extent. However, The "Grain for Green" intensified the unbalance between food production and ecological protection [52]. Chaoyang County is a typical agricultural county population-based which the agricultural population accounts for 94.1% of the total population. From 2000 to 2010, a large number of forest land near residential areas was felled into cultivated land, especially in the Xiaoling river basin. These conversions made the landscape fragmentation increased [53], and the landscape pattern more complex. Therefore, the ecological risk of the landscape in the Daling River and Xiaoling River basin increased, and the higher risk areas of the Xiaoling River basin have expanded significantly. From 2010 to 2018, the awareness of ecological protection increased, and government control was stricter, the number of cultivated land and forest land tended to stabilize.

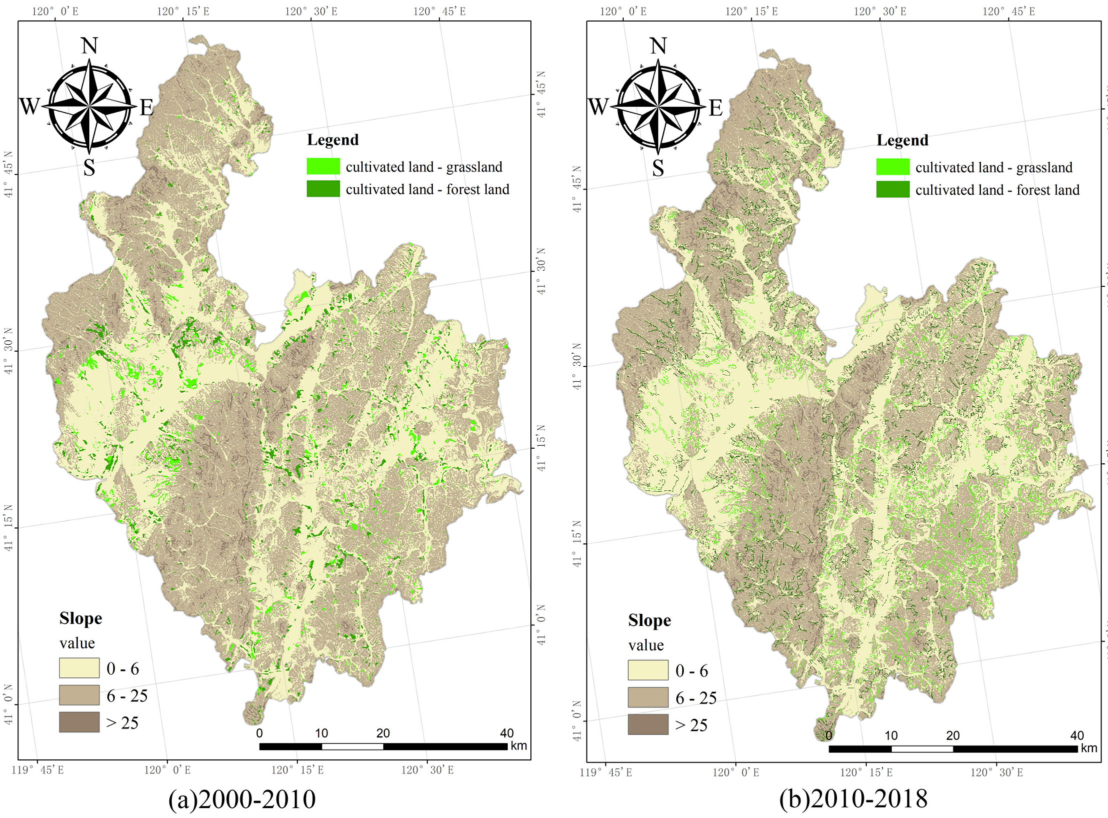


Figure 8. Implementation of the "Grain for Green" project in study area (**a**) 2000–2010 (**b**) 2010–2018.

The expansion of rural settlements is an incentive for changes in ecological risks. According to statistics, the population of Chaoyang County was 627,477, 566,350, and 552,489 in 2000, 2010, and 2018, respectively, which showed a trend of decreasing. In theory, the area of rural settlements increases with the increase in population, and vice versa. In fact, the area of rural settlements in most provinces in China showed an increasing trend between 2002 to 2010 [54]. From 2000 to 2010, the area of rural settlements land in Chaoyang increased from 11,567.34 hm^2 to 22,082.49 hm^2. The main reason for this factor is that the rapid industrialization process provided a large number of non-agricultural employment opportunities, which increased the income level of the agricultural population and enabled them to improve their living standards, increase housing area, and build new homesteads. The expansion of settlements during this period lacked macro guidance from policies, so it showed a disorderly expansion. And the landscape fragmentation and isolation landscape index of built-up land increased [55,56], thus the loss index was increased [57]. From 2010 to 2018, driven by the tide of urbanization, the expansion of rural homesteads weakened.

Deforestation can also lead to increased landscape ecological risk. The forest land is rich in species, and the ecosystem structure is relatively stable [58]. So, the landscape ecological risk of the forest land is low. Chaoyang County lacked a unified management organization and policy system for land use in the early stage. And the forest land in the southeast of the area suffered huge destruction, either reclaimed as cultivated land or degraded to grassland. The landscape ecological risk increased in this period.

4.2. Ecological Risk Management Suggestions

On the basis of the results, and in view of the need for ecological risk management and sustainable economic and social development in Chaoyang County. The following suggestions are put forward. On the one hand, as the main production and living space, the ecological risk of the Daling River and Xiaoling River Basin needs to be focused on.

The urban expansion will continue for a long time. Nevertheless, it doesn't mean that cultivated land can be occupied without limits. Cultivated land protection and agricultural intensification must be taken seriously. Moreover, the government should increase the utilization intensity and stop the unreasonable expansion of built-up. On the other hand, the policy of forest land protection should be implemented continuously to protect existing forest land in the northwest and southwest from damage. And for the damaged forest land, corresponding biological measures or engineering measures should be taken to prevent further degradation and gradually restore the damaged vegetation. It is worth noting that the restoration of forest land is a gradual process, selecting reasonable tree species for sowing according to local conditions. The government should mainly use government finance to guide social capital to invest in this process.

4.3. The Innovations and Limitations

In previous studies, landscape ecological risk assessments were mostly based on landscape pattern indexes, focusing on the analysis of the impact of indicators such as fragmentation and separation on landscape ecological risks [37,59,60]. However, we analyzed from the perspective of land use/land cover change into the indicator system which could highlight the influence of human-induced factors. Several studies have shown that most land-use changes are driven by humans [61]. However, the impact of specific pressure processes was neglected. In future research, we should explore how to construct an evaluation method for comprehensive land use landscape patterns and ecological pressure index systems. Incorporate indicators such as pesticide and fertilizer input, water pollution monitoring data, and soil quality into the evaluation system.

Spatial autocorrelation analysis was applied to explore the spatial epidemiological characteristics of tuberculosis and identified and visualized the main clustering areas of the disease (predicting areas with a high incidence of diseases) [62]. At present, we introduced this method into ecological risk assessment. And we found that the ecological risks in Chaoyang County also had certain agglomeration characteristics in the spatial distribution. Since the manpower and material resources that the government can invest in is limited, spatial autocorrelation analysis can guide us to focus on the HH risk agglomeration areas. And alerted us to the sudden deterioration of the ecological environment in the LH risk agglomeration areas. Furthermore, we can better identify the risk pattern from another angle. On the whole, a large local risk level difference may lead to the expansion of the large risk range, so we identify different areas and give different strategies.

5. Conclusions

In this study, we revealed the influence of land use/land cover change on distribution and pattern of landscape ecological risk in Chaoyang County. 2010 is an inflection point of the three-year ecological risk change in the study area. The ecological risks showed increased and decreased trends in the period of 2000 to 2010 and 2010 to 2018, respectively. In general, the ecological risk of the river basin presented a "high level", i.e., poor status, with development-driven built-up land sprawl and part of deforestation. It could be concluded that occupying cultivated land for built-up and large-scale deforestation were two of the main factors contributing to the increase of ecological risk from the perspective of the land-use change. Anthropogenic activities (characterized by stability of land use structure) had less impact on the area of lower and lowest ecological risk which mainly covered by extensive forest land with high terrain. In addition, HH (located in the Daling River and Xiaoling River basin) and LH (located in southwest and southeast of the study area) risk agglomeration should be paid more attention to prevent environment degradation due to interactions with neighboring risk areas.

Our study investigated the effects of land-use change on ecological risk and also gave a novel perspective to investigate the pattern of ecological risk. Spatial autocorrelation could deepen the research on ecological risk assessment, identify key risk areas and provide support for government departments to adopt different policy measures according to different ecological risk patterns. Our study could give some advice to management of ecological risk for policymakers.

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