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# Spatial-temporal changes of landscape ecological risk in the Liuchong river basin from the perspective of production-life-ecological space

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Promoting the construction of ecological civilization and sustainable development in karst mountainous areas by analyzing the spatial and temporal changes of landscape ecological risks is critical in karst mountainous watersheds. In this study, the land use transfer matrix, landscape ecological risk evaluation model, ecological contribution rate of land use change, and spatial autocorrelation analysis were combined to quantitatively analyze the land use and landscape ecological risk of a typical karst watershed, Liuchong River Basin, over the past 20 years. The results revealed that: 1) From 2000 to 2020, the functional classification of land use in the Liuchong River Basin was dominated by the woodland ecological space, and the most significant shifting characteristics were the increase in the area of watershed ecological space and industrial production space and the decrease in woodland ecological space, with shifts in the middle reaches of the Liuchong River being the most drastic; 2) Generally, the change of the regional landscape pattern was related to the transformation of the land use function type of "production-life-ecological space," and the spatial aggregation of ecological risk level showed a gradual weakening trend. 3) The conversion of the watershed ecological space to the grassland ecological and agricultural production spaces, the conversion of urban living space to the agricultural production space, and the conversion of the rural living space to the agricultural production space were the dominant factors affecting ecological improvement, whereas the conversion of the woodland ecological space to the grassland ecological space, the woodland ecological space to the agricultural production space, and the grassland ecological space to the agricultural production space contributed to ecological degradation. The study findings can be used as a reference for the coordinated development of "production-life-ecological space" in karst watersheds and provide a scientific basis for ecological environmental protection and sustainable utilization.

## KEYWORDS

landscape ecological risk, production-life-ecological space, spatial and temporal changes, Liuchong river basin, ecological risk

# 1 Introduction

Ecological risk is the amount of risk an ecosystem and its components are exposed under natural or anthropogenic disturbances (Yu et al., 2022). Landscape ecological risk assessment can reflect the effect of landscape patterns on ecological processes and functions (Liu et al., 2022; Ran et al., 2022). Urban growth patterns in China exhibit a trend of sprawling expansion, which has led to a considerable increase in the level of urbanization and a drastic expansion in the scale of land use. However, urbanization has caused several problems, including encroachment on productive agricultural and ecological land, deepening landscape fragmentation, and ecological pollution. These problems have resulted in an imbalance in the ratio of the production-life-ecology spatial structure (Bai et al., 2019; Qi, 2020; Zhang et al., 2021; Lu et al., 2022). Especially in the karst mountainous areas of southwest China, the frequent natural and human activities and the increasing level of economic development and urbanization have exerted a considerable ecological and environmental pressure on the ecologically fragile and environmentally change-sensitive karst mountain belt. In this context, the 18<sup>th</sup> Party Congress proposed ecological civilization construction to control the development intensity and adjust the spatial structure and balance population, resources and environment, and unify economic, social and ecological benefits, for promoting intensive and efficient production space, livable and moderate living space, and beautiful ecological space, with nature restoration, good land for agriculture, and a beautiful home with blue sky, green land, and clean water for future generations. Thus, the construction of ecological civilization has gradually become the prime focus of national land space development.

By providing novel perspectives for regional ecological risk research, the landscape pattern index method has become a research hotspot (Guo and Guo, 2022; Li et al., 2023). To construct landscape ecological risk evaluation models, corresponding parameters are chosen according to the specificity of landscape patterns in various research regions. This approach has been applied in many risk control regions, yielding excellent results. For example, Hayes et al. used a relative risk model to assess regional ecological risk in the near-coastal marine environment of northwest Washington and identified ship traffic, mountainous urban, and agricultural land use, and shoreline recreational activities as the ecological risk factors in the marine nearshore area (Hayes and Landis, 2004). Ayre analyzed (Ayre and Landis, 2012) a forested landscape in northeastern Oregon from a landscape disturbance, habitat, and ecological resource perspective based on a Bayesian network model with an ecological risk assessment framework. Paukert conducted a landscape-scale ecological risk assessment of land use, waterway development and diversion, and human development in the lower Colorado River basin at four watershed scales (Paukert et al., 2011). Studies in China have investigated the factors affecting landscape ecological risk (LER) from the perspective of landscape ecology and elucidated the dynamics of LER and its spatial and temporal patterns. Kang constructed a LER index for the Manas River basin from the proportion of landscape components during 2000–2015 and then compared the distribution of various levels of LER and spatial and temporal distribution in the region (Kang et al., 2020). Based on the landscape ecological risk

index and geographically weighted regression model, Wang revealed the interconnection between the levels of LER and urban expansion in Yuanzhou district from 2000 to 2018 (Wang et al., 2021). Liu constructed an ecological risk evaluation model from the watershed scale and water source protection zone scale to examine the spatial and temporal changes of ecological risk in the Miyun Reservoir watershed during 1990–2018 (Liu et al., 2023). Lan evaluated the spatial and temporal evolution characteristics of ecological risk in Guilin city at the overall and county scales based on the spatial correlation between land use and ecological risk in the city during 2000–2020 (Lan et al., 2023). Although studies on LER evaluation are relatively mature, limited research has been conducted on LER in karst mountains (Wang et al., 2022a). In addition, most studies have focused on a single land use type, and fewer studies have analyzed LER from the perspective of “production-life-ecological space” (Su et al., 2020; Wang et al., 2022b).

The continuous development of the global economy, technology, and population has further strengthened the effect of human activities on the natural environment. The karst region has considerably higher ecosystem fragility and environmental vulnerability than other regions because of its unique geological and climatic conditions. Being an important region, effectively promoting the healthy development of ecological environment in the watershed is a concern. Therefore, this study analyzed the spatial and temporal evolution patterns of ecological risk in the Liuchong River Basin from the spatial perspective of “three lives,” based on the land use data of 2000, 2010, and 2020. Furthermore, by integrating the results with geographical information system (GIS) spatial analysis and LER index, the spatial evolution of production-ecology in the context of rapid socio-economic development was clarified. The spatial evolution process of life ecology and LER in the context of rapid socio-economic development was considered to provide a reference for ecological risk management and landscape pattern optimization in typical karst mountainous basins.

## 2 Materials and methods

### 2.1 Study area

Liuchong River is the largest first-order tributary of the Wujiang River system, with a total length of 273.4 km and a natural drop of 1,243 m. Because of geomorphology and hydrogeology constraints, the river is tortuous, with deep valley, narrow surface and large drop. The Liuchong River Basin is located in Bijie City, northwestern Guizhou Province and southwestern Zhenxiong County, Yunnan Province, with longitude and latitude ranges of 104°20′–160°07′E and 26°31′–27°30′N, respectively. The total area of the basin is 10,874 km<sup>2</sup> (Figure 1). The basin is a typical karst mountainous watershed with karst landform development and complex topography. The watershed belongs to a subtropical cool and humid monsoon climate, with moderate water and heat resources. The annual average temperature is approximately 18°C, and the precipitation is concentrated in May–September, with an annual average precipitation of 848.6–1394.4 mm. Because of the fragile ecological environment in the watershed, the ecological landscape security in the watershed is has attracted considerable research attention because of the continuous

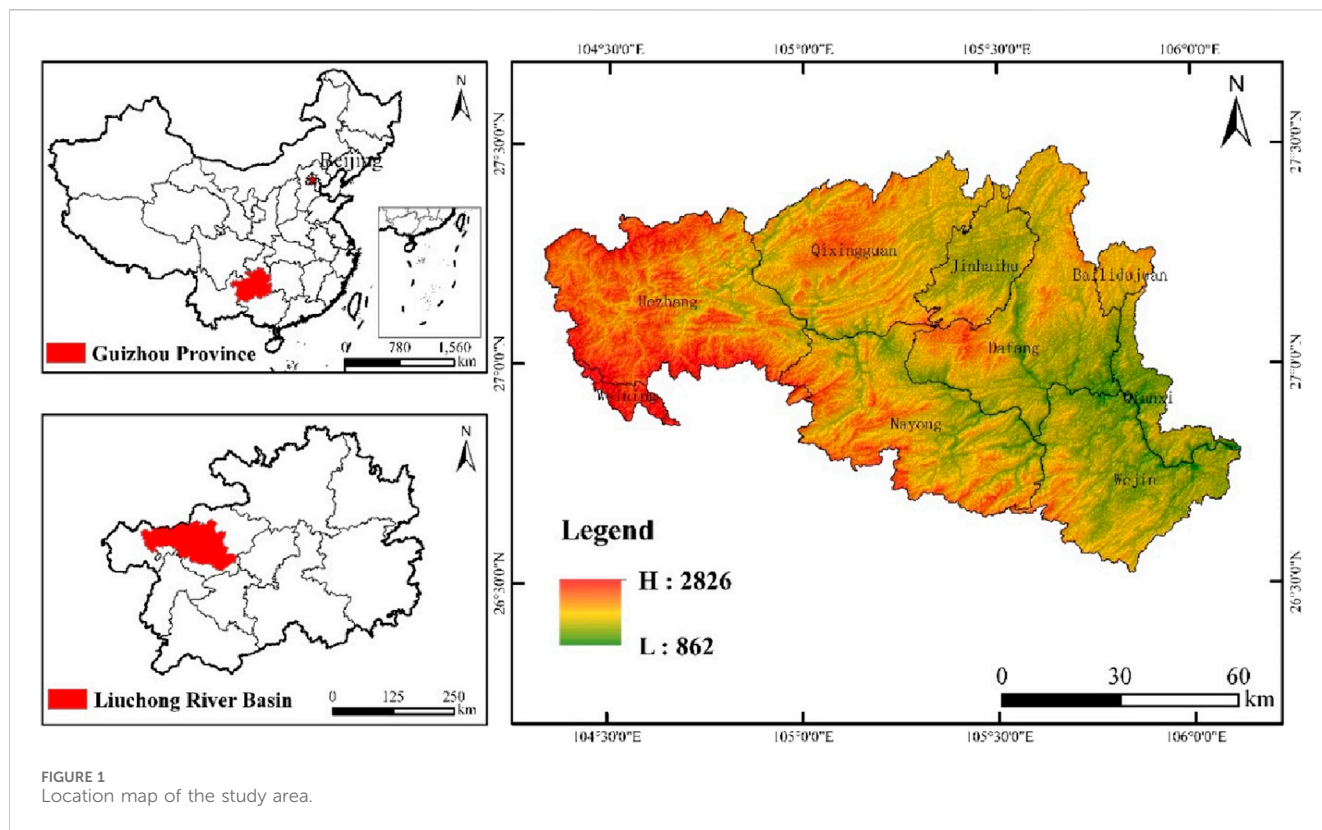


FIGURE 1 Location map of the study area.

TABLE 1 Classification of dominant land use functions.

Primary functional classification	Secondary functional classification	Tertiary land classification
Production space	Agricultural space	11 (paddy field), 12 (dry land)
	Industrial space	53 (industrial and mining construction land)
Living space	Urban space	51 (urban residential land)
	Rural space	52 (rural residential land)
Ecological space	Forested space	21 (forested land), 22 (shrub land), 23 (open forest land), and 24 (other forest lands)
	Grass space	31 (high-cover grassland), 32 (medium-cover grassland), and 33 (low-cover grassland)
	Water space	41 (rivers and canals), 42 (lakes), 43 (reservoir ponds), 44 (permanent glaciers), 45 (mudflats), 46 (mudflats)
	Other spaces	61 (sandy land), 62 (Gobi), 63 (saline land), 64 (marshland), 65 (bare land), 66 (bare rocky gravel land)

urbanization and accelerated comprehensive development and utilization of the watershed in the past 20 a.

## 2.2 Data

Land use data of the Liuchong River Basin for three periods from 2000 to 2020 (2000, 2010, 2020) were obtained from the Resource and Environment Science Data Center of the Chinese Academy of Sciences (<http://www.resdc.cn>), with the spatial resolution of 30 m. Using

ArcGIS 10.6, the land use data were projected and transformed, spliced, and cropped. Based on the development objective of building the efficient production space (PS), livable space (LS), and beautiful ecological space proposed by the government and the actual situation of the watershed and according to the land use classification system, PLES was classified into eight secondary categories, namely agricultural production space, industrial production space, urban living space, rural living space, forest ecological space, grassland ecological space, water ecological space, and other ecological spaces (Table 1).

TABLE 2 Calculation method for the landscape pattern index and its ecological meaning.

Landscape pattern index	Formula and its ecological meaning
Landscape fragmentation	$C_i = n_i/A_i$ ; where $n_i$ is the number of patches of landscape type $i$ ; and $A_i$ is the total area of landscape type $i$ . Landscape fragmentation characterizes the degree of fragmentation of landscape types, reflecting the complexity of landscape spatial structure, which is caused by natural or man-made disturbance of the landscape from a single, homogeneous, and continuous whole tends to complex, heterogeneous, and discontinuous patch mosaic process
Landscape Separation	$N_i = \frac{1}{2} \sqrt{n_i/A} \cdot P_i$ , $P_i = A/A_i$ ; where $A$ indicates the proportion of the total area of the landscape patches. The degree of landscape separation characterizes the degree of separation of various elements or individual distribution of patches in a landscape type, and the greater the degree of separation is, the more dispersed the landscape is in terms of geographical distribution and the more complex the landscape distribution is
Number of landscape sub-dimensions	$F_i = 2 \ln(p_i/4)/\ln A_i$ , where $p_i$ is the perimeter of the landscape type and indicates the complexity of shape and spatial stability of the landscape patches
Landscape disturbance degree	$U_i = aC_i + bF_i + cD_i$ ; where: $a$ , $b$ , and $c$ denote the corresponding weights of landscape fragmentation, separation, and dominance, respectively, based on a previous study (Zhan et al., 2009), and are assigned the corresponding weights of 0.5, 0.3, and 0.2, with $a + b + c = 1$ . The landscape disturbance degree indicates the degree to which the ecosystems represented by various landscape types are disturbed by human activities
Landscape fragility	The landscape vulnerability index is a critical quantitative index that indicates the stability of the landscape to maintain its physical and chemical properties under the influence of external factors, also called the landscape external disturbance resistance, with reference to existing research results (Chen et al., 2022a), and combined with the actual situation of the study area. The eight secondary land categories in the study area were assigned values from low to high: urban living space, 1; rural living space, 2; woodland ecological space, 3; grassland ecological space, 4; agricultural production space, 5; watershed ecological space, 6; industrial production space, 7; and other ecological spaces, 8, with normalized sizes of 0.03, 0.06, 0.08, 0.11, 0.14, 0.14, 0.17, 0.19, and 0.22, respectively
Landscape loss degree	$R_i = U_i \times S_i$ ; $R_i$ indicates the degree of loss of natural attributes of the ecosystems represented by various landscape types when subjected to natural and anthropogenic disturbances

## 2.3 Methods

### 2.3.1 Division of the LER assessment unit

To make the LER index reflect the ecological risk status caused by landscape changes in a certain area, a quantitative expression was used to portray the degree of spatial ecological risk, according to the basic requirements and principles of landscape ecology, and using 2–5 times the average patch area for the grid is appropriate, considering the study area and landscape spatial heterogeneity. After repeated debugging, a square grid of 3 km × 3 km was selected as the study area. The center point of each grid was considered to be the sampling point, totaling 1240 sampling points. The ecological risk index was calculated for each of the 1240 cells in the study area based on this grid division and used as the ecological risk value of the sample area center point for spatial interpolation analysis.

### 2.3.2 The LER assessment model

To examine the spatial and temporal variability and characteristics of landscape ecological risk in the Liuchong River Basin, a landscape ecological risk evaluation model was constructed using the calculation of the LER from previous studies (Su et al., 2020).

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

Here,  $ERI_k$  denotes the regional LER index of the  $k$ -th sampling area,  $n$  denotes the total number of landscape types,  $A_{ki}$  denotes the area of landscape type  $i$  in the  $k$ -th plot,  $A_k$  denotes the total area of the  $k$ -th plot, and  $R_i$  denotes the landscape loss degree index, which is obtained by the product operation of landscape fragility  $S_i$  and landscape disturbance  $U_i$ . The formula and ecological meaning of

the corresponding calculation of landscape pattern index are presented in Table 2.

### 2.3.3 Ecological contribution rate of PLES land use transformation (LEI)

LEI refers to the land use types leading to ecological risk changes. Quantifying the impact of land use type shifts on the ecological environment from both positive and negative aspects can help in discriminating between the land use types that affect changes in regional ecological quality and identifying the dominant factors for changes in the regional ecological environment (Liang et al., 2022). It is calculated using the following formula:

$$LEI = (LE_{t1} - LE_{t0})LA/TA \quad (2)$$

where LEI indicates the ecological contribution of the regional land use transformation type. The value of LEI ranges from -1 to 1, with a positive number indicating a positive contribution that increases the ecological risk, and a negative number indicating a negative contribution that decreases the ecological risk.  $LE_{t1}$  and  $LE_{t0}$  refer to the ecological risk index of a specific land type before and after transformation, respectively;  $LA$  is the area of that change type;  $TA$  is the total area of the study area.

## 3 Results

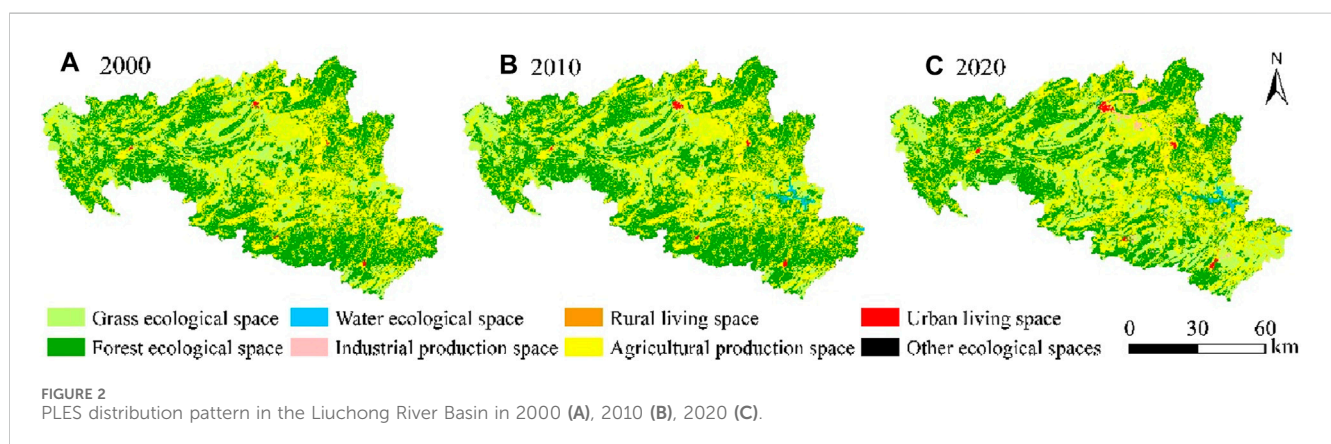
### 3.1 Quantitative change and type shift of land use in the PLES

The changes of PLES area and the proportion of PLES in the Liuchong River Basin for 3 years are presented in Table 3, revealing



TABLE 3 Area and change of land use types in the Liu Chong River Basin from 2000 to 2020.

Land use Functional classification	Area/km <sup>2</sup>			Area of change/km <sup>2</sup>	
	2000	2010	2020	2000–2010	2010–2020
Forest ecological space	93629.73	95618.42	93202.41	1988.69	−2416.01
Grass Ecological Space	31878.41	29584.88	31331.05	−2293.53	1746.16
Water Ecological Space	406.02	687.99	1046.64	281.97	358.64
Other Ecological Spaces	40.25	29.73	30.39	−10.51	0.66
Urban Living Space	251.95	358.33	681.24	106.38	322.90
Rural Living Space	240.57	270.24	310.16	29.68	39.91
Industrial production space	106.62	244.18	1167.96	137.56	923.78
Agricultural production space	49624.98	49386.65	48403.52	−238.33	−983.13

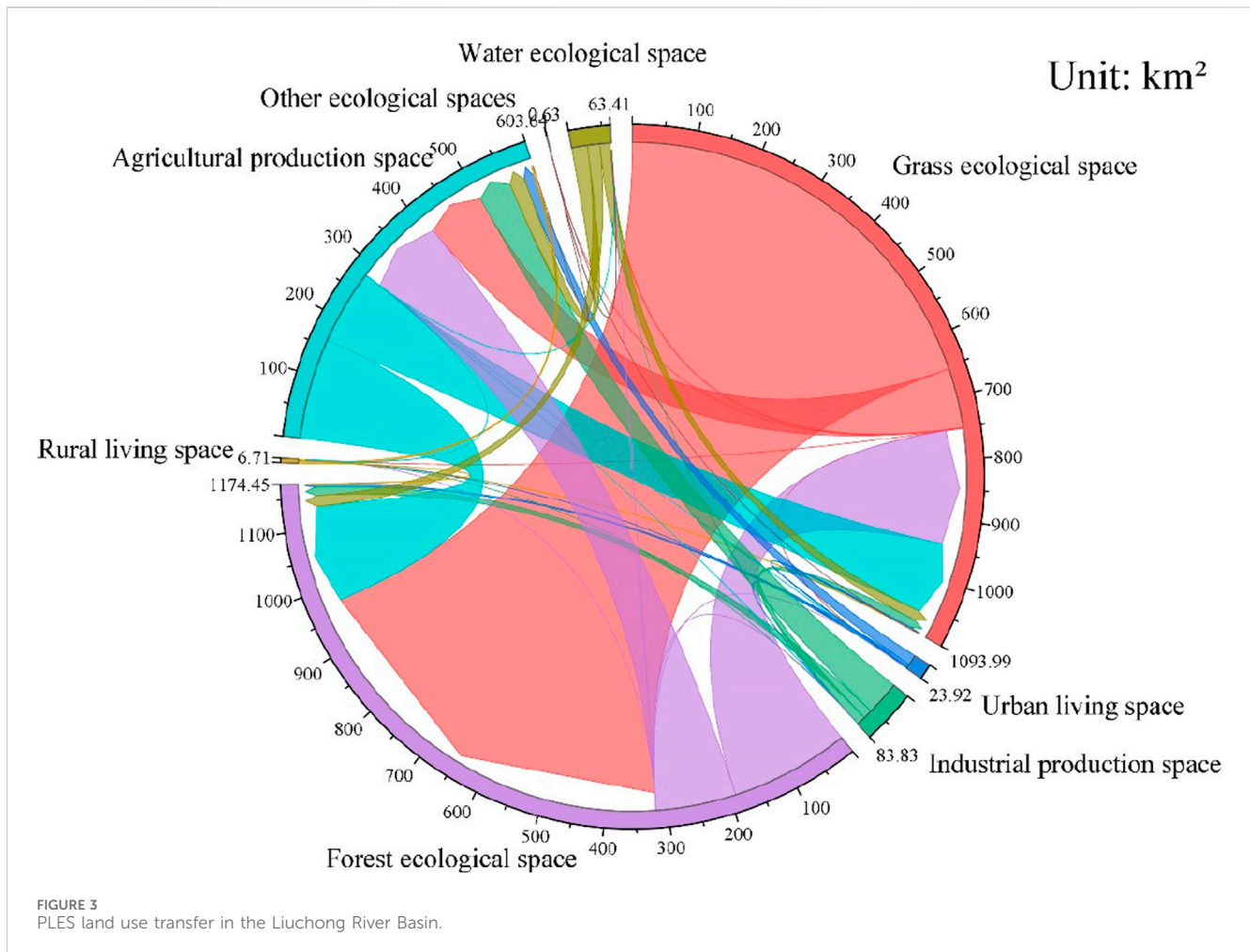


that the area of “production-life-ecological space” in the Liuchong River Basin varied greatly from 2000 to 2020, and the land use function classification in 2000–2020 is woodland ecological space, followed by an agricultural production space. During the study period, the area of woodland and grassland ecological spaces exhibited an overall decrease, with the woodland ecological space of 93629.73 km<sup>2</sup> in 2000 decreasing to 93202.41 km<sup>2</sup> in 2020, grassland ecological space shrinking from 31878.41 km<sup>2</sup> in 2000–31331.05 km<sup>2</sup> in 2020, and the agricultural production space shrinking from 49624.98 km<sup>2</sup> in 2000–48403.52 km<sup>2</sup> in 2020. The area of the water ecological space showed an increasing trend, from 406.02 km<sup>2</sup> in 2000 to 1046.64 km<sup>2</sup> in 2020, whereas the area of other ecological spaces did not significantly change. From the perspective of the living space, the area of urban living space and rural living space increased from 251.95 to 240.57 km<sup>2</sup> in 2000 to 681.24 and 310.16 km<sup>2</sup> in 2020, respectively. From the perspective of the production space, the area of the industrial production space continued to increase from 106.62 km<sup>2</sup> in 2000 to 1167.96 km<sup>2</sup> in 2020, whereas the area of the agricultural production space exhibited a slightly decreasing trend from 49,624.98 km<sup>2</sup> in 2000 to 48,403.52 km<sup>2</sup> in 2020.

According to the change patterns in the distribution of PLES in the study area from 2000 to 2020 (Figure 2), the industrial production space underwent the most rapid expansion, the area

of urban living, rural living, and watershed ecological spaces exhibited a gradual increase, corresponding to a gradual reduction in the area of agricultural production space, and the woodland ecological space and grassland ecological space exhibited a slight change. Although the area of industrial production space decreased in 2000, which was only sporadically distributed around the urban living space, by 2020, a large expansion was observed along the perimeter of the city, with significant changes in the area.

PLES land use area, in addition to the quantitative increase or decrease, also shows distinct types of transfer. Figure 3 reveals that during the 20-year period, the area transferred out of woodland ecological space was 3667.46 km<sup>2</sup>, reaching the historical maximum, of which 655.33 km<sup>2</sup> was transformed into the grassland ecological space, and 160.90 km<sup>2</sup> was transformed into the agricultural production space. The amount of transfer in was only 319.34 km<sup>2</sup>, whereas the amount of transfer out was considerably larger than the amount of transfer in, which indicated that the area of woodland ecological space decreased during the study period. Second, the amount of the agricultural production space transferred out was 3459.94 km<sup>2</sup>, mainly to the woodland ecological and grassland ecological spaces, with an area of 222.91 km<sup>2</sup>, and the amount of transfer in was 280.11 km<sup>2</sup>, converted from the grassland ecological and woodland ecological spaces, with an area of



279.30 km<sup>2</sup>. The grassland ecological space was the type with the most amount of land transfer in, and the area converted from woodland ecological and grassland. The area transformed from woodland ecological space and grassland ecological space amounted to 750.09 km<sup>2</sup>.

### 3.2 Temporal variation in ecological risk in PLES landscapes

Based on the PLES land use raster data of 2000, 2010, and 2020 in the Liuchong River Basin, the ecological risk indexes of each landscape were calculated using Fragstats 4.2 software and combined with the formula 1 and formulas in Table 2; subsequently, the results were compiled (Table 4). As depicted, for over 20 years, the index of fragmentation of agricultural production space remained unchanged; the degree of separation first decreased and subsequently increased, indicating that the aggregation of its landscape type has increased; the fragmentation and separation of industrial production space and rural living space were high, and the values decreased year by year, indicating that their distribution in space is highly dispersed; and the ecological stability increased considerably with the increase in the area. The increase in the area of the urban living space covered the surrounding small patches, resulting in a decrease in fragmentation

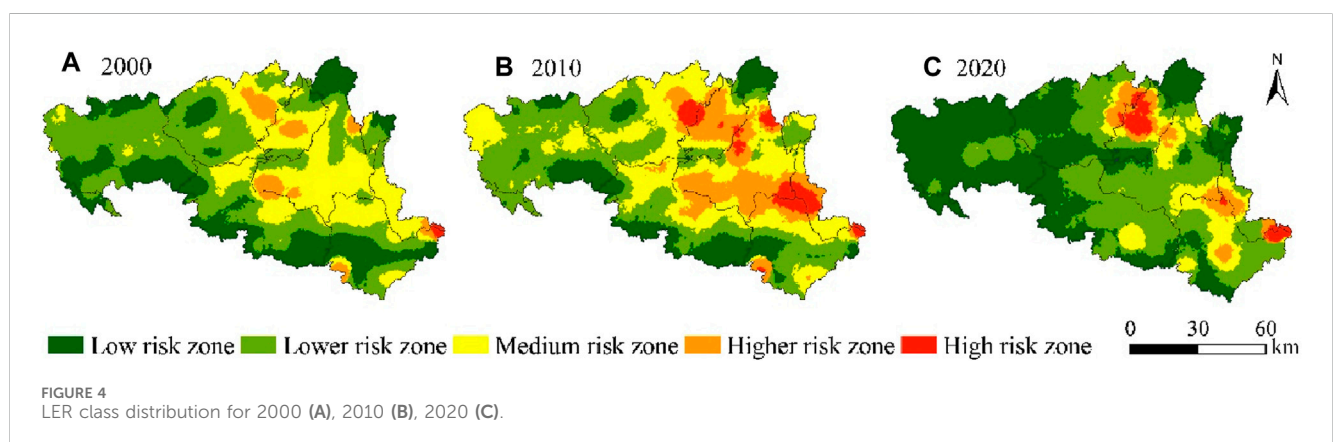
and separation of the urban living space annually. The fragmentation of the woodland ecological space increased, whereas the fragmentation and separation of grassland, water, and other ecological spaces continued to decline, with the decline for other ecological spaces being linear. Second, the values of the sub-dimension of each landscape type in the Liuchong River Basin were low and exhibited a decreasing trend, indicating that the shape of the landscape types in the study area tended to be simple and the intensity of disturbance by human activities was decreasing. The change trend of the disturbance index of each landscape type was similar to that of the sub-dimension; however, the disturbance index of rural living space and other ecological space was large, with both reached the historical peak at the beginning of the study, indicating that the disturbance index of human activities on rural living space and other ecological space was large in 2000, which reached the historical minimum in 2020, indicating a decrease in the disturbance of human activities on the landscape.

### 3.3 Analysis of spatial and temporal changes in LER

The ecological risk distribution maps of the study area in 2000, 2010, and 2020 were obtained through kriging interpolation. According to the natural breakpoint method, the

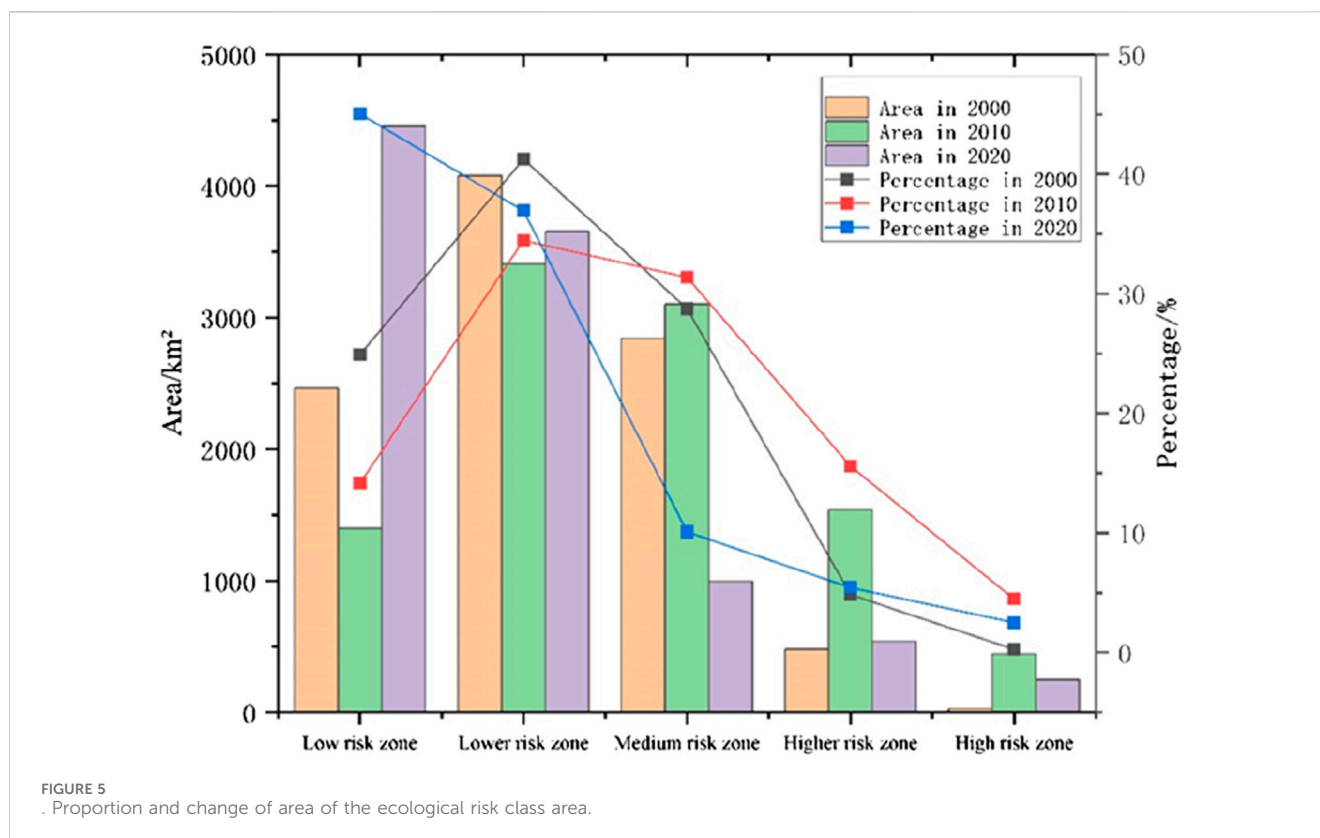
TABLE 4 Land Use Transfer Matrix for production-life-ecological space in the Liuchong River Basin (Unit: km<sup>2</sup>).

Type	Year	Fragmentation degree	Separation degree	Separation dimension	Interference degree	Loss degree
Rural Living Space	2000	0.014	0.1	0.396	0.117	0.016
	2010	0.014	0.097	0.396	0.115	0.016
	2020	0.014	0.1	0.002	0.038	0.005
Industrial production space	2000	0.07	9.608	0.293	2.976	0.565
	2010	0.045	2.81	0.339	0.933	0.177
	2020	0.035	1.008	0.004	0.321	0.061
Urban Living Space	2000	0.004	0.937	0.354	0.354	0.011
	2010	0.003	0.547	0.375	0.24	0.007
	2020	0.002	0.348	0.006	0.106	0.003
Rural Living Space	2000	0.113	7.082	0.308	2.243	0.135
	2010	0.087	4.838	0.321	1.559	0.094
	2020	0.082	4.503	0.007	1.393	0.084
Forest ecological space	2000	0.004	0.049	0.411	0.099	0.008
	2010	0.004	0.048	0.412	0.099	0.008
	2020	0.005	0.059	0.002	0.021	0.002
Grass Ecological Space	2000	0.009	0.104	0.398	0.115	0.013
	2010	0.009	0.112	0.396	0.117	0.013
	2020	0.008	0.088	0.003	0.031	0.003
Water Ecological Space	2000	0.041	3.485	0.329	1.132	0.192
	2010	0.008	0.574	0.374	0.251	0.043
	2020	0.007	0.506	0.005	0.156	0.027
Other Ecological Spaces	2000	0.063	31.581	0.221	9.55	2.101
	2010	0.06	29.713	0.225	8.989	1.978
	2020	0.039	11.157	0.015	3.369	0.741



ecological risk of the study area landscape was classified into low, lower, medium, higher, and high ecological risk zones (Figure 4).

The distribution of the ecological risk level of the landscape strongly correlated with the distribution of PLES land types, with high-risk and medium-high-risk areas in the northeast and southeast



regions exhibiting a trend of “scattering-clustering” from 2000 to 2020, and expanding outward by 2020. The aforementioned areas are dominated by the industrial production and urban living space, and the strong human activities lead to the instability of the ecosystem. High landscape separation and sub-dimension number considerably influence the formation of the landscape pattern and are sensitive to external disturbances. For the medium-risk areas, the aggregation areas located in the central-western and south-central regions gradually declined. Furthermore, lower-risk areas were concentrated in the periphery of medium-risk areas, including the woodland ecological and grassland ecological spaces, with low landscape fragmentation and weak human activities. During 2010–2020, this space increased considerably, and most medium-risk areas converted into lower-risk areas. The low ecological risk areas were concentrated in the peripheral areas, and in 2020, a large distribution in the northwest of the watershed, mostly the woodland ecological space, with low population density and complex and diverse topography, was observed. These low-risk areas are not easily disturbed by human activities, leading to the predominance of these areas.

The area and proportion of each risk level area were counted to analyze the changes in increase and decrease of the ecological risk (Figure 5). From the temporal perspective, in 2000, the ecological risk was dominated by low-risk, lower-risk, and medium-risk areas, among which the lower-risk area occupied the largest area, reaching 4078.91 km<sup>2</sup>, which was 41.25% of the total study area. The ecological risk situation deteriorated from 2000 to 2010 and improved considerably from 2010 to 2020. This phenomenon indicates that the ecological environment quality improved and the ERI level decreased during the study period.

### 3.4 Spatial autocorrelation analysis of ecological risk in the landscape

The global Moran’s I value of ERI in the study area in 2000, 2010, and 2020 were 0.3881, 0.3456, and 0.3100, respectively, all of which are greater than 0, indicating that ERI is positively correlated in space and exhibits a certain spatial convergence. Furthermore, the global Moran’s I value from 2000 to 2020 exhibited an overall decreasing trend, reflecting the weakening of the ERI and spatial convergence. Compared with the global Moran’s I, the local Moran’s I accurately reflects the spatial distribution of ecological risk values in the landscape. As displayed in Figure 6, high-high (HH) and low-low (LL) clustering dominated ecological risk values in the three periods, as presented in the LISA clustering of ecological risk indices in the Liuchong River Basin from 2000 to 2020 (Figure 6), with the high concentration exhibiting a northeast-southeast trend. By 2020, the HH agglomeration declined and part of the internal grid became nonsignificant. By contrast, LL agglomerations were distributed around the study area and were dispersed. The agglomerated areas exhibited a gradual convergence, whereas the dispersed areas showed gradual dispersion. High-low (HL) and low-high (LH) phenomena are rare and discrete in distribution. Quantitatively, both the spatial autocorrelation and the number of grids in the HH clustered areas declined over time, and the number of positively correlated grids that passed the significance test ( $p > 1$ ) decreased. Therefore, the spatial clustering characteristics of ERI in the Sixchon River basin are weakening.



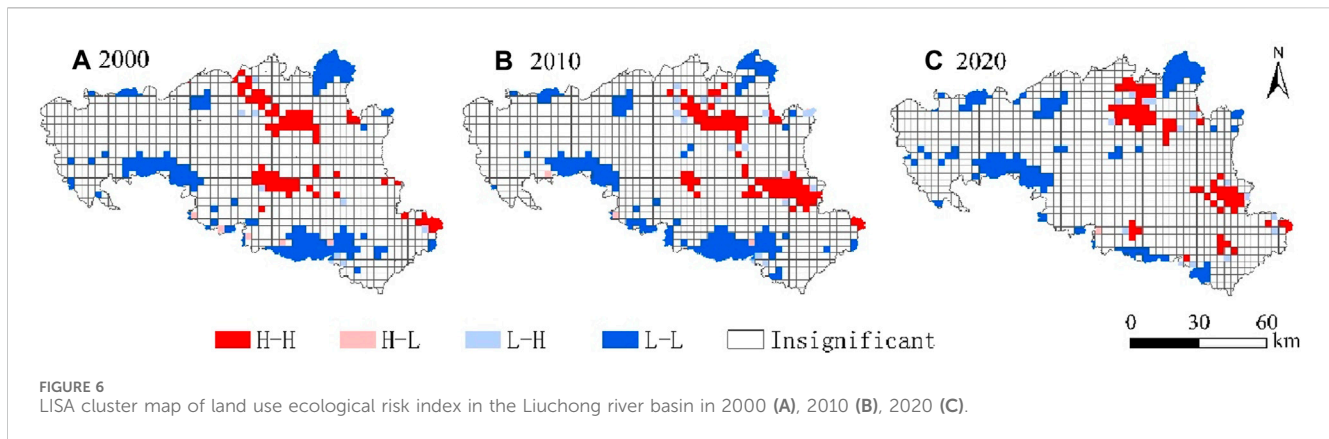


TABLE 5 Landscape index calculation results of production-life-ecological space.

Transformation of "production-life-ecological space" (leading to improvement of ecological environment)	Index change	Contribution share (%)	Transformation of the "production-life-ecological space" (leading to ecological degradation)	Index change	Contribution share (%)
III -VI	0.000000000043	2.05	VI-V	-0.0000003654	8.25
III - I	0.000000000202	9.65	VI-I	-0.0000000799	1.80
II -VI	0.000000000079	3.76	V-VI	-0.0000017575	39.69
IV-II	0.000000000055	2.62	V-I	-0.0000002609	5.89
IV-V	0.000000000085	4.07	VI-I	-0.0000004836	10.92
IV - I	0.000000000612	29.19	I-III	-0.0000000980	2.21
VII -VI	0.000000000590	28.15	I-II	-0.0000003156	7.13
VII -V	0.000000000068	3.25	V-I	-0.0000006928	15.65
VII - I	0.000000000343	16.38	I-VII	-0.0000001495	3.38

Note: I is agricultural production space; II, is industrial production space; III, is urban living space; IV, is rural living space; V is woodland ecological space; VI, is grassland ecological space; VII, is water ecological space.

### 3.5 Effect of PLES land use conversion on ecological risk

In terms of the contribution of the dominant PLES land use conversion (Table 5), the dominant factors affecting ecological improvement are the conversion of the watershed ecological space to the grassland ecological and agricultural production spaces, the conversion of the urban living space to the agricultural production space, and the conversion of the rural living space to the agricultural production space in the Liuchong River Basin from 2000 to 2020, with a combined contribution of 83.37%. By contrast, the conversion of the woodland ecological space to the grassland ecological space, the woodland ecological space to the agricultural production space, and the grassland ecological space to the agricultural production space were the dominant factors leading to ecological degradation, with a combined contribution of 63.26%. The expansion of the urban living space during the study period was attributed mainly to the reduction of the agricultural production space. The transformation of the agricultural production space to the urban living space

indirectly changes landscape fragmentation, landscape separateness, and landscape fractional dimension index, eventually increasing the regional ecological risk.

## 4 Discussion

Examining the interactions between PLES land use changes and landscape patterns in the Liuchong River Basin, a typical karst basin, can help analyze the correlation at the macro level. In this study, we investigated the land use and LER changes in the Liuchong River Basin from the perspective of PLES. We constructed a LER assessment model by referring to existing studies (Yang et al., 2018; Qi, 2020; Chen and Shi, 2021; Chen et al., 2022b; Wang et al., 2022c; Guo and Guo, 2022; Li and Wu, 2022; Liang et al., 2022). Furthermore, by using land use change ecological contribution ratio and spatial autocorrelation analysis, we quantitatively analyzed the LER of the Liuchong River Basin in karst areas. By comparing data of different years, we summarized the spatial and temporal change patterns of LER in the region in the past 20 years. The results revealed that, first, the stability of

the ecosystem in the karst region was severely disturbed by human activities. In this study, the functional classification of land use in the Liuchong River Basin in the past 20 years was dominated by the woodland ecological space, but a trend of decreasing woodland ecological space was observed, whereas the area of the industrial production space increased. This phenomenon indicates that the impact of current human activities on the karst ecosystem is intensifying, and effective measures are required to protect and restore the ecosystem. Second, the distribution of high and low ecological risk levels in the landscape is strongly correlated with the distribution of PLES land types. The high-risk and medium-high-risk areas are distributed in the northeast and southeast regions, which are dominated by the agricultural production, industrial production, and urban living spaces and are disturbed by human activities. Although the lower and low-risk areas are mostly in the periphery of the medium-risk area, including the woodland ecological and grassland ecological spaces. Therefore, targeted measures should be enacted to protect high-risk and medium-high-risk areas. Moreover, coordinated management with agriculture, industry, and towns should be conducted to ensure environmental quality and ecosystem stability. Finally, the conversion of the watershed ecological space to the grassland ecological and agricultural production spaces, the conversion of the urban living space to the agricultural production space, and the conversion of the rural living space to the agricultural production space are the dominant factors affecting ecological improvement. This phenomenon indicates that the agricultural production and grassland ecological spaces should be protected and restored to ensure ecological environmental protection in karst areas. Further, to promote agricultural modernization and sustainable development, the occupation of land resources by urban and rural living spaces should be reduced and transformed into the agricultural production space as much as possible.

This study has some shortcomings. First, LER assessment is a complex process requiring the consideration of multiple uncertainties. These factors determine the comprehensive evaluation results. When assessing ecological risks, these factors determine the integrated evaluation results. In the LER assessment of complex karst areas, the method and process should be improved. Second, this study selected only the Liuchong River Basin as the study object and did not cover other regions. In the future, more study sites can be selected for cross-sectional comparative analysis to improve the generalizability and reliability of the results. Finally, we did not consider the differences in human activities and influence, especially under different topographic conditions, human production, living, and other activities. These factors considerably influence the evolutionary process of PLES land use, spatial and temporal patterns, and the extent of their effect on the ecosystem. Therefore, these factors were not included to elucidate the complexity and diversity of land use and its ecological environment in the Liuchong River Basin. Future research should use improved methodology and advanced technologies in land use analysis and ecological risk evaluation, and expand the scope of the study area to achieve effective protection and management of karst watershed ecosystems.

## 5 Conclusion

In this study, the land use classification system was constructed from the perspective of PLES based on the land use cover data in

2000, 2010, and 2020. Using GIS spatial analysis technology and Fragstats 4.2 software, the land use transfer matrix, LER evaluation model, ecological contribution rate of land use flow, and spatial autocorrelation analysis were combined. Furthermore, the spatial and temporal patterns of PLES land use and its LER in the Liuchong River Basin over the past 20 years were quantitatively analyzed. The conclusions are as follows:

- (1) From 2000 to 2020, the functional classification of land use in the Liuchong River Basin was dominated by the woodland ecological space, accounting for more than 53% of the total area, and the industrial production space underwent the most rapid expansion. The most significant transfer characteristics of PLES land use were the increases in the ecological space of watershed and the area of industrial production space and a decrease in the woodland ecological space; the transfer was the most drastic in the middle reaches of the main stream of the Liuchong River, whereas the surrounding areas of Hezhang County are stable ecosystems due to higher altitude and less disturbance by human activities.
- (2) The distribution of high and low LER levels correlated strongly with the distribution of PLES land types, with high-risk and medium-high-risk areas distributed in the northeast and southeast regions, and medium-risk areas clustered in the west-central and south-central regions of the basin and exhibiting a gradual decrease. Furthermore, the lower and lowest risk areas were concentrated in the periphery of the medium-risk areas, including the woodland ecological and grassland ecological spaces, with low landscape fragmentation and weakly affected by human activities.
- (3) The spatial aggregation characteristics of ecological risk levels gradually weakened from 2000 to 2020. HH and LL are concentrated in distribution, HL and LH phenomena are rare and discrete in distribution, and the clustering of HH and LL is obvious in local areas, showing a northeast-southeast trend and a strip-like distribution in space. These areas predominately comprise the agricultural production space, industrial production space, and urban living space and are strongly affected by anthropogenic activities.
- (4) The conversion of the watershed ecological space to the grassland ecological and agricultural production spaces, urban living space to the agricultural production space, and rural living space to agricultural production space were the predominant factors contributing to ecological improvement, with a combined contribution of 83.37%. By contrast, the conversion of woodland ecological space to grassland ecological space, woodland ecological space to agricultural production space, and the grassland ecological space to the agricultural production space were the factors contributing to ecological degradation.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

JR: Conceptualization, Data curation, Project administration, Writing—original draft, Writing—review and editing. YD: Data curation, Formal Analysis, Methodology, Project administration, Writing—original draft, Writing—review and editing. PH: Methodology, Writing—original draft. HL: Data curation, Methodology, Writing—original draft.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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